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(12) **United States Patent**
Kanbara et al.

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(45) **Date of Patent: Jan. 2, 2018**

(54) **FUEL INJECTION VALVE AND FUEL INJECTION VALVE CONTROLLER**

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(73) Assignee: **DENSO CORPORATION**, Kariya (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 86 days.

(21) Appl. No.: **15/170,023**

(22) Filed: **Jun. 1, 2016**

(65) **Prior Publication Data**

US 2016/0356251 A1 Dec. 8, 2016

(30) **Foreign Application Priority Data**

Jun. 5, 2015 (JP) 2015-114556
Mar. 7, 2016 (JP) 2016-43629

(51) **Int. Cl.**
F02M 51/06 (2006.01)
F02M 45/10 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***F02M 45/10*** (2013.01); ***F02M 47/027*** (2013.01); ***F02M 51/0603*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC F02M 47/027; F02M 51/0603; F02M 51/0607; F02M 51/0639; F02M 51/0642;
(Continued)

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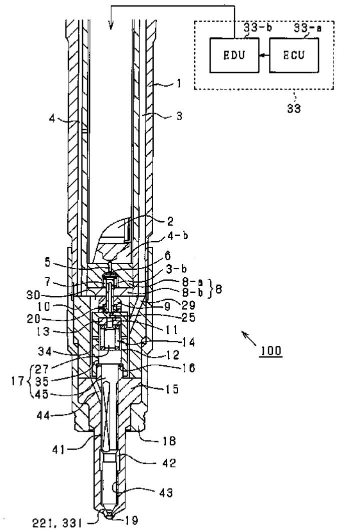
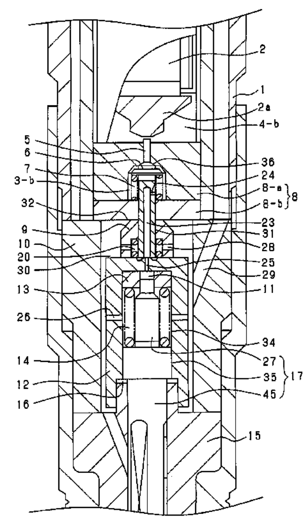
Primary Examiner — Erick Solis
(74) *Attorney, Agent, or Firm* — Nixon & Vanderhye P.C.

(57) **ABSTRACT**

A fuel injection valve includes a body including a first chamber that supplies fuel of a first pressure, a second chamber that supplies fuel of a second pressure, and an injection hole, a valve chamber member including a valve chamber connectable to the first chamber and the second chamber, a control chamber member including a control chamber connectable to the first chamber, a needle pressed by pressure of fuel in the control chamber in a direction that causes fuel injection from the injection hole to stop, an actuator, a valve element that selectively connects the first chamber, second chamber, and the valve chamber according to the actuator extending and contracting, and a transmission mechanism that when the actuator extends, transmits the force to the needle as a force in a direction that causes fuel to be injected from the injection hole.

33 Claims, 26 Drawing Sheets





(51) **Int. Cl.**
F02M 47/02 (2006.01)
F02M 63/00 (2006.01)

(52) **U.S. Cl.**
CPC ***F02M 51/0607*** (2013.01); ***F02M 63/0026*** (2013.01); *F02M 2200/21* (2013.01); *F02M 2200/704* (2013.01)

(58) **Field of Classification Search**
CPC F02M 51/0653; F02M 51/0657; F02M 51/0682; F02M 63/0026; F02M 2200/21; F02M 2200/704
USPC 123/472; 239/585.5
See application file for complete search history.

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FIG. 1

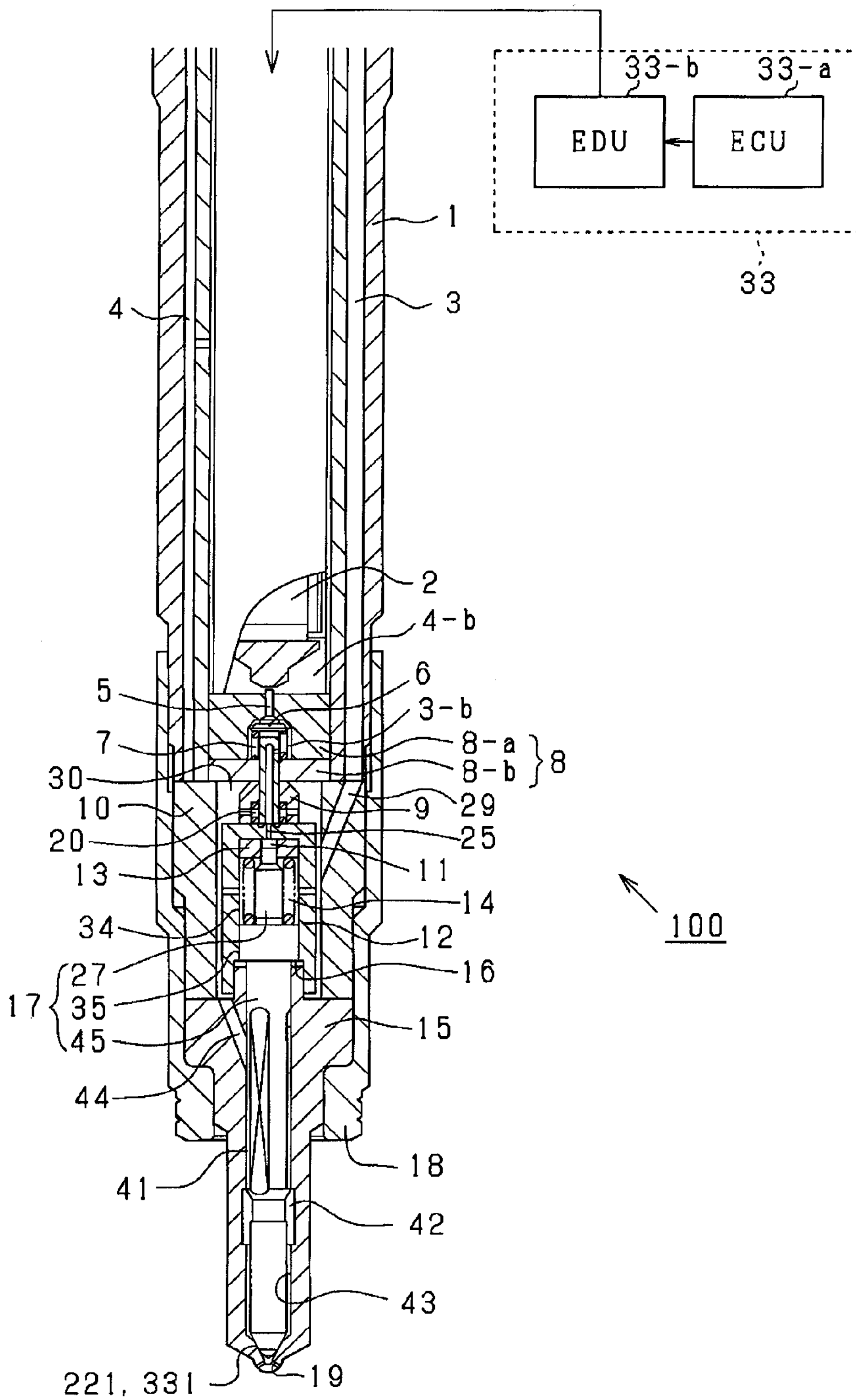

33-b
33-a
EDU
ECU
33
1
3
4
2
4-b
5
6
3-b
7
8-a
8-b
8
30
10
9
29
20
25
13
11
14
34
12
100
27
16
17
35
45
15
44
18
41
42
43
221, 331
19

FIG. 2

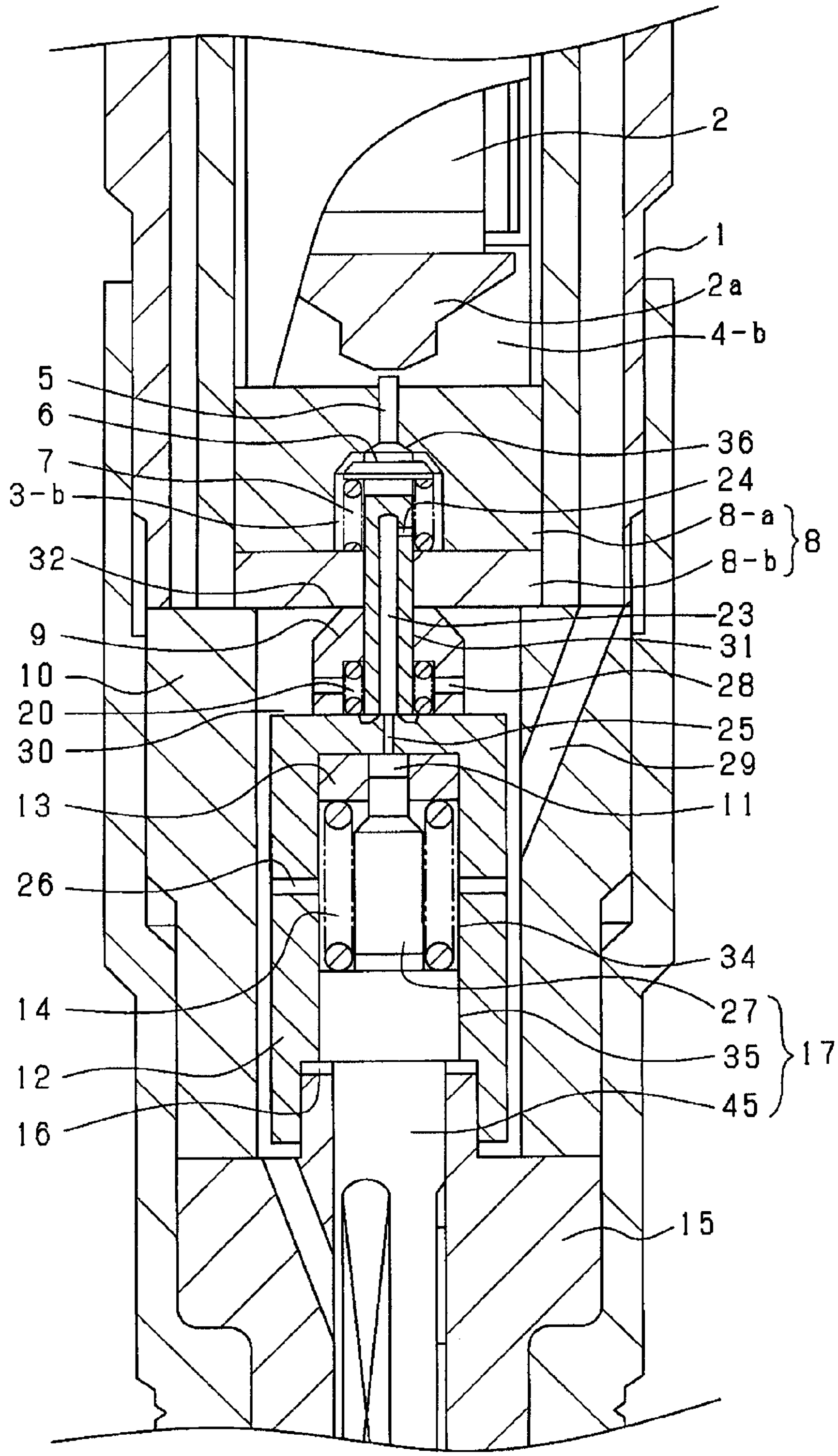

2
1
2a
4-b
5
6
36
7
24
3-b
8-a
8
32
8-b
23
9
31
10
28
20
25
30
29
13
11
26
34
14
27
17
35
12
45
16
15

FIG. 3

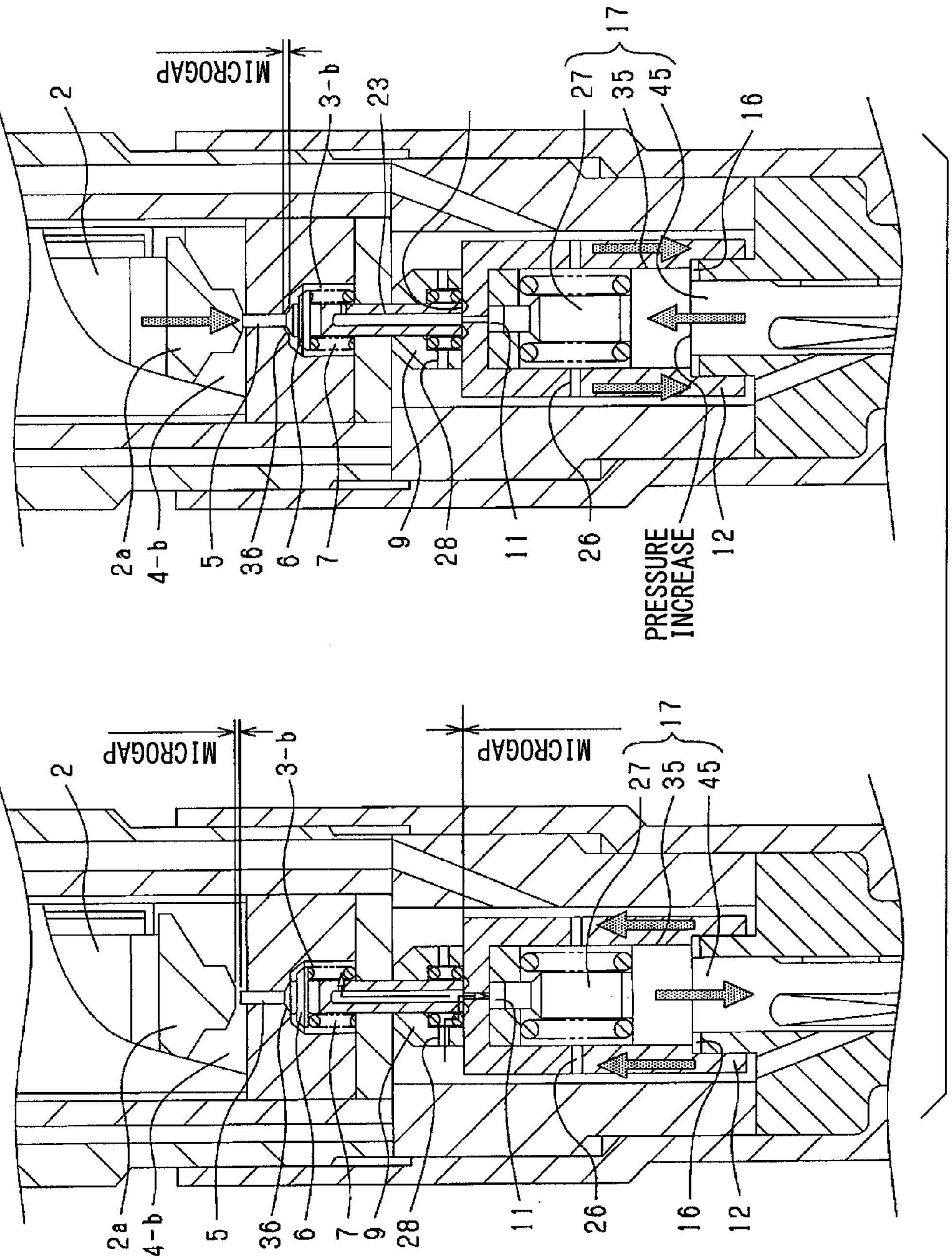

NEEDLE OPENING
(VALVE OPENING)
NEEDLE CLOSING
(VALVE CLOSING)
MICROGAP
MICROGAP
MICROGAP
PRESSURE
INCREASE
2
2a
3-b
4-b
5
6
7
9
11
12
16
17
23
26
27
28
35
36
45

FIG. 4

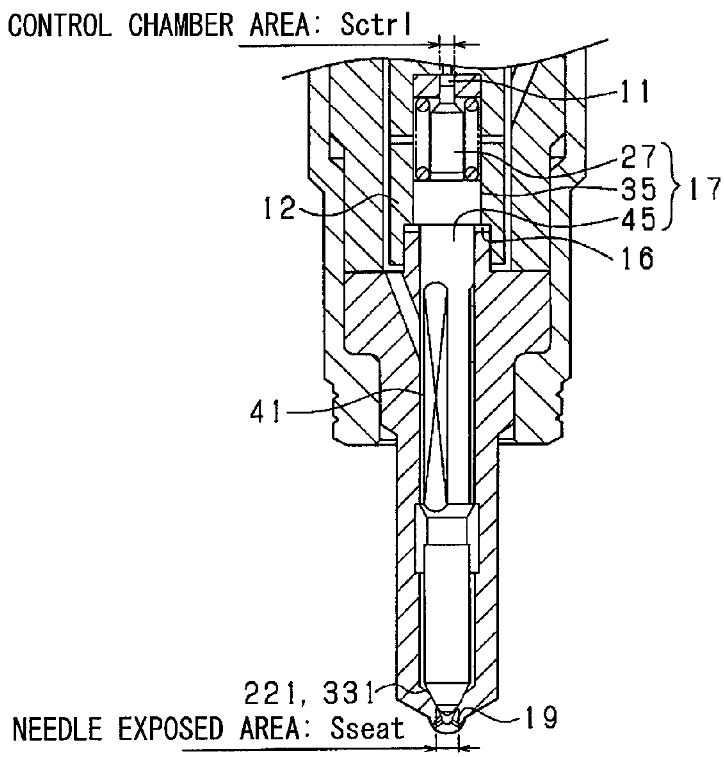

CONTROL CHAMBER AREA: Sctrl
11
27
35
45
17
12
16
41
221, 331
NEEDLE EXPOSED AREA: Sseat
19

FIG. 5

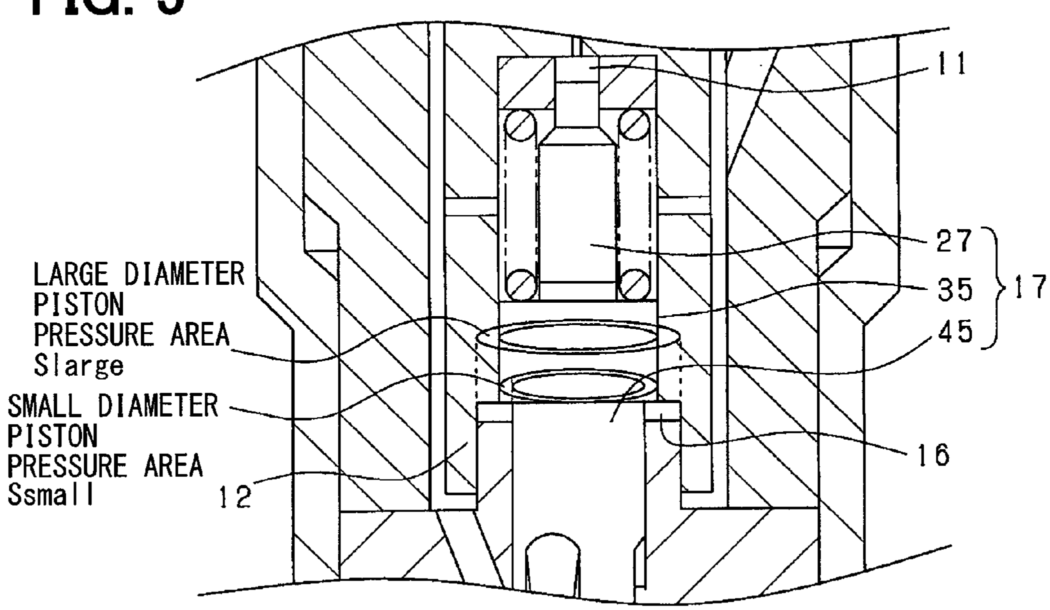

11
27
35
45
17
LARGE DIAMETER PISTON PRESSURE AREA Slarge
SMALL DIAMETER PISTON PRESSURE AREA Ssmall
12
16

FIG. 6

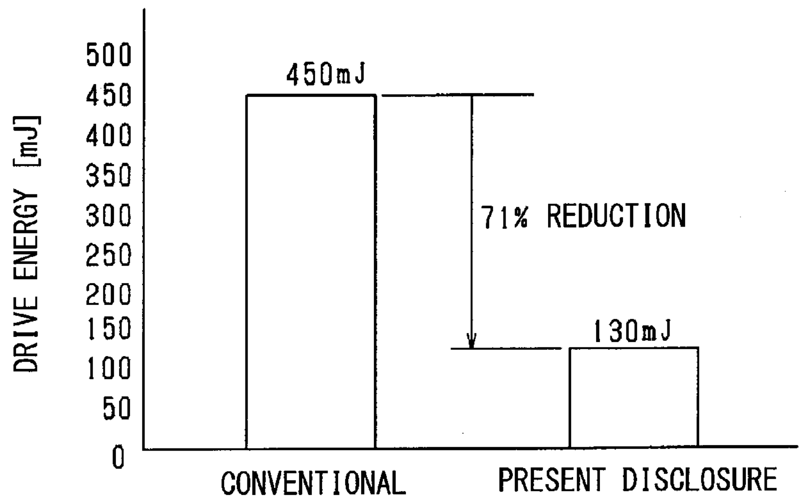

DRIVE ENERGY [mJ]
500
450
400
350
300
250
200
150
100
50
0
450mJ
71% REDUCTION
130mJ
CONVENTIONAL
PRESENT DISCLOSURE

FIG. 7

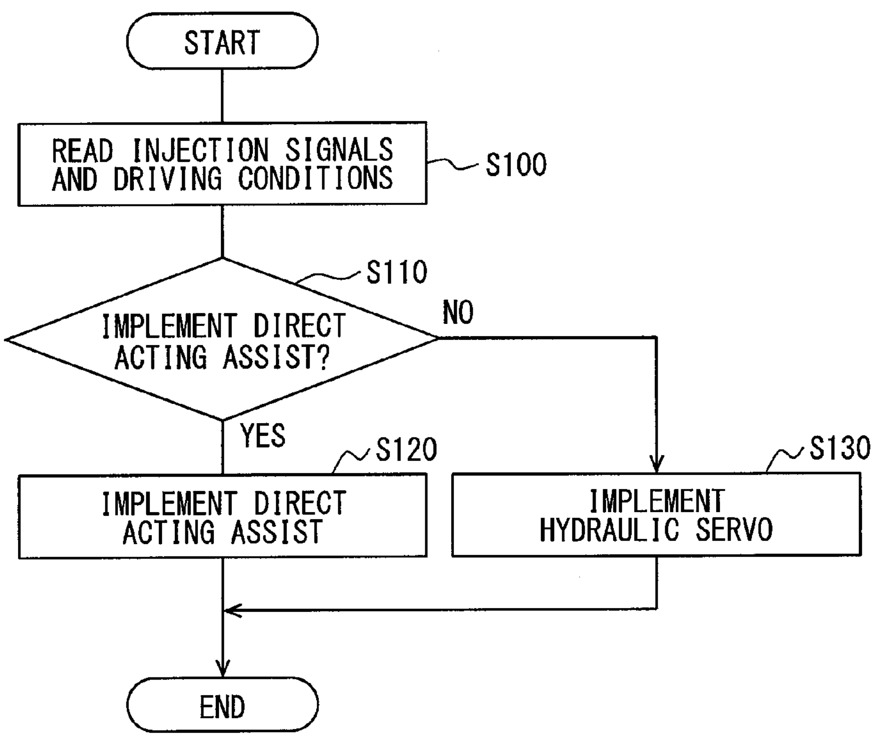

START
READ INJECTION SIGNALS AND DRIVING CONDITIONS
S100
S110
IMPLEMENT DIRECT ACTING ASSIST?
NO
YES
S120
IMPLEMENT DIRECT ACTING ASSIST
S130
IMPLEMENT HYDRAULIC SERVO
END

FIG. 8

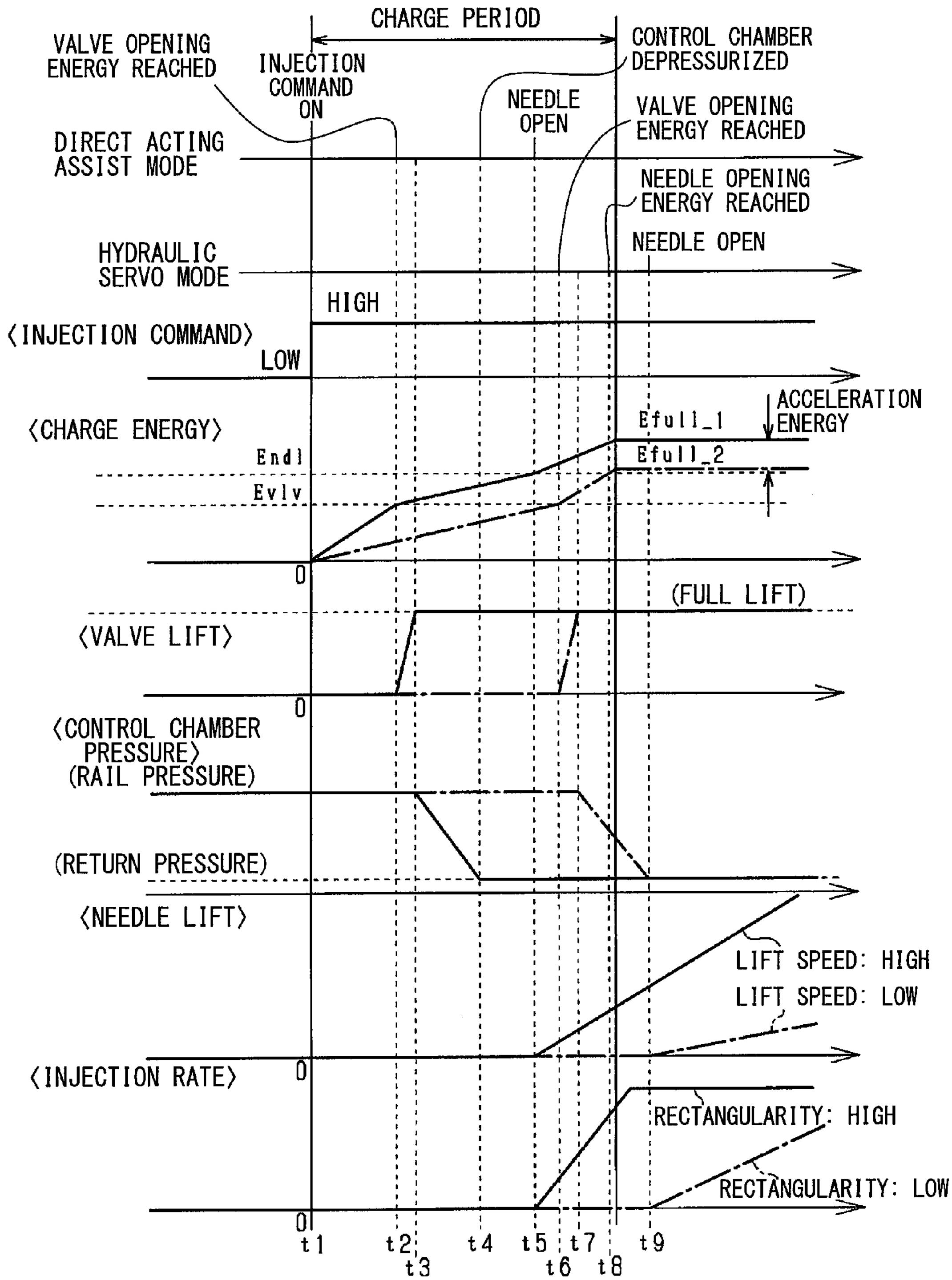

CHARGE PERIOD
VALVE OPENING ENERGY REACHED
INJECTION COMMAND ON
CONTROL CHAMBER DEPRESSURIZED
NEEDLE OPEN
VALVE OPENING ENERGY REACHED
DIRECT ACTING ASSIST MODE
NEEDLE OPENING ENERGY REACHED
NEEDLE OPEN
HYDRAULIC SERVO MODE
HIGH
⟨INJECTION COMMAND⟩
LOW
⟨CHARGE ENERGY⟩
Efull_1
ACCELERATION ENERGY
Efull_2
Endl
Evlv
0
(FULL LIFT)
⟨VALVE LIFT⟩
0
⟨CONTROL CHAMBER PRESSURE⟩
(RAIL PRESSURE)
(RETURN PRESSURE)
⟨NEEDLE LIFT⟩
LIFT SPEED: HIGH
LIFT SPEED: LOW
⟨INJECTION RATE⟩
0
RECTANGULARITY: HIGH
RECTANGULARITY: LOW
0
t1
t2
t3
t4
t5
t6
t7
t8
t9

FIG. 9

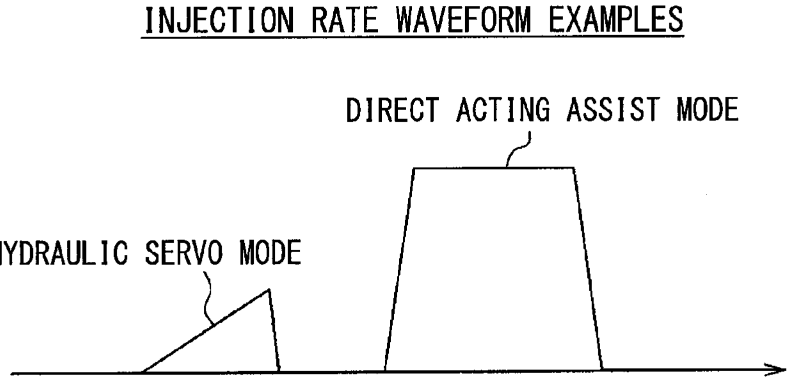

INJECTION RATE WAVEFORM EXAMPLES
DIRECT ACTING ASSIST MODE
HYDRAULIC SERVO MODE

FIG. 10

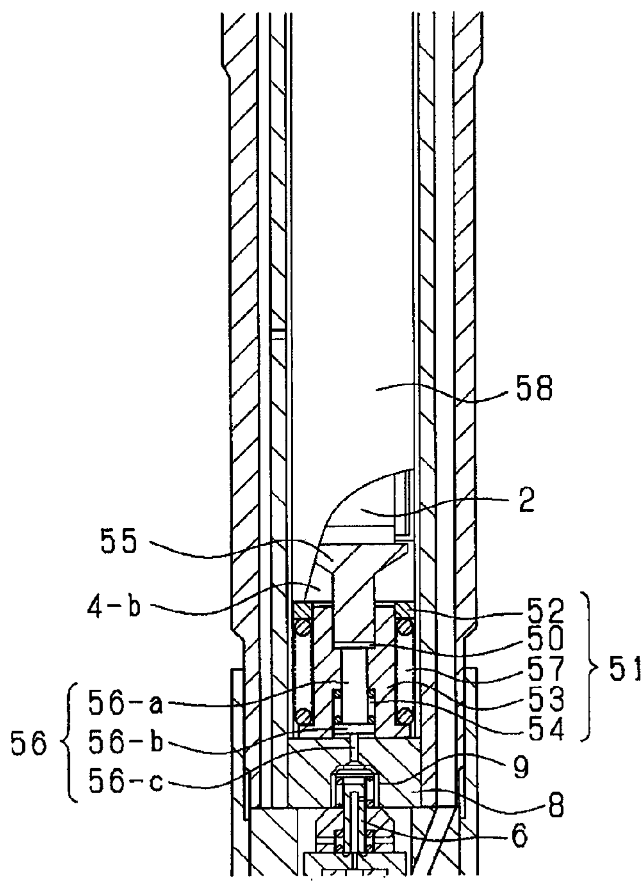

58
2
55
4-b
52
50
57
53
54
51
56-a
56-b
56-c
56
9
8
6

FIG. 11

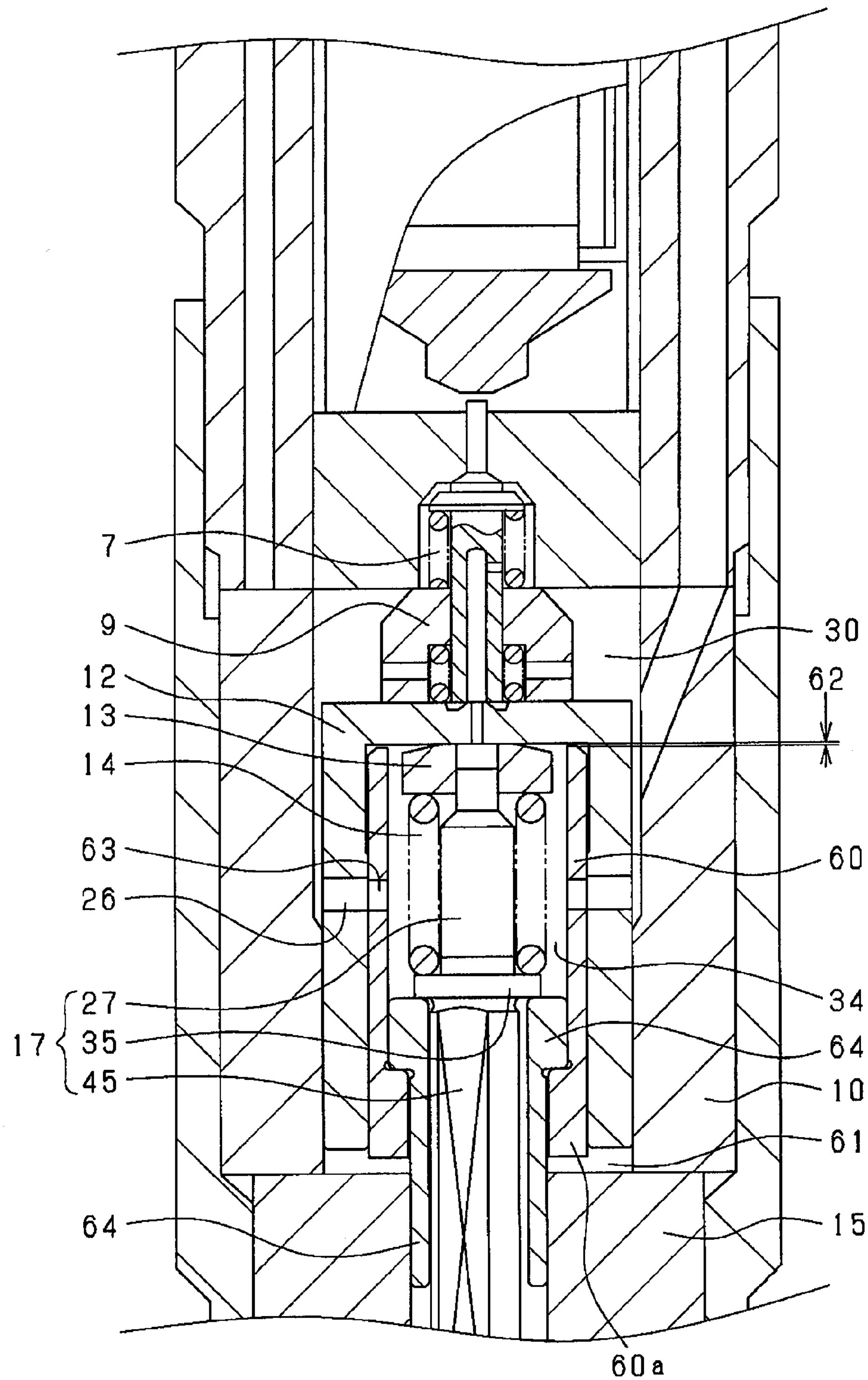


FIG. 12

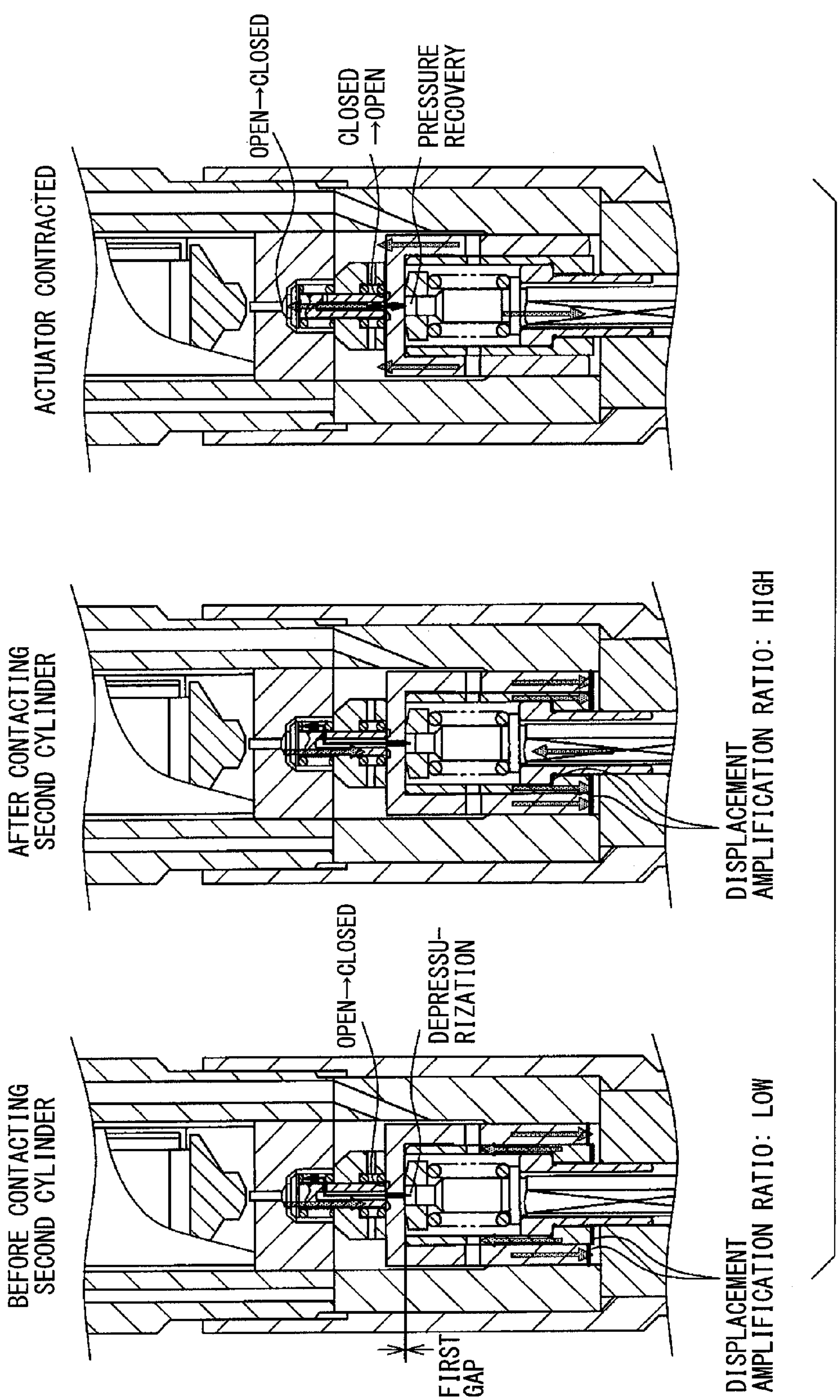

BEFORE CONTACTING
SECOND CYLINDER
OPEN→CLOSED
DEPRESSU-
RIZATION
FIRST
GAP
DISPLACEMENT
AMPLIFICATION RATIO: LOW
AFTER CONTACTING
SECOND CYLINDER
DISPLACEMENT
AMPLIFICATION RATIO: HIGH
ACTUATOR CONTRACTED
OPEN→CLOSED
CLOSED
→OPEN
PRESSURE
RECOVERY

FIG. 13

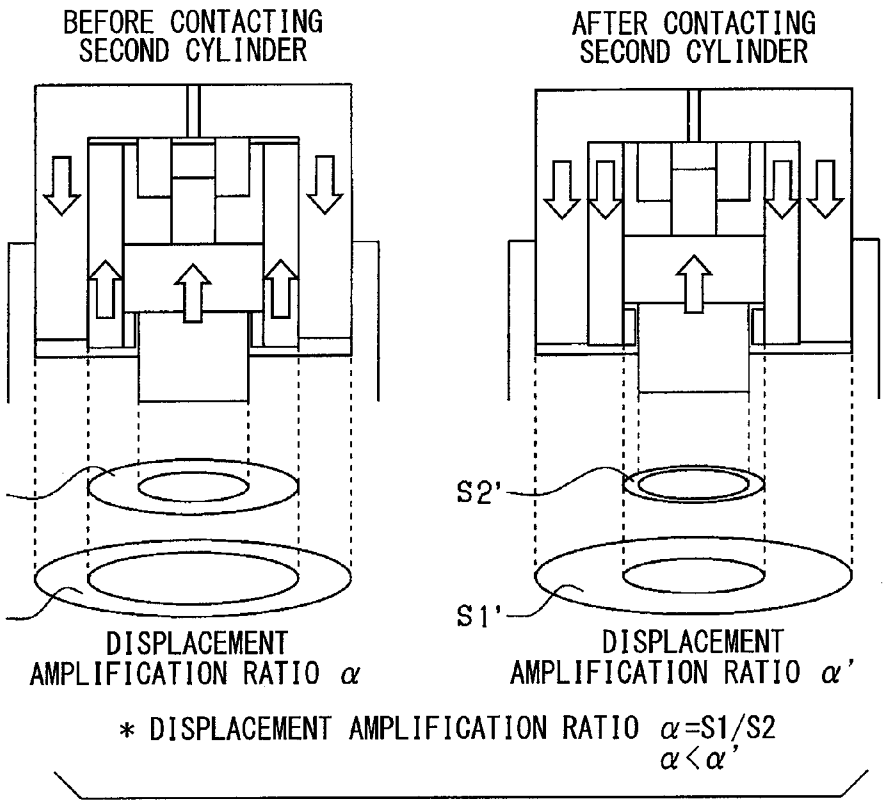

BEFORE CONTACTING SECOND CYLINDER
AFTER CONTACTING SECOND CYLINDER
S2
S1
S2'
S1'
DISPLACEMENT AMPLIFICATION RATIO α
DISPLACEMENT AMPLIFICATION RATIO α'
* DISPLACEMENT AMPLIFICATION RATIO α=S1/S2
α<α'

FIG. 14

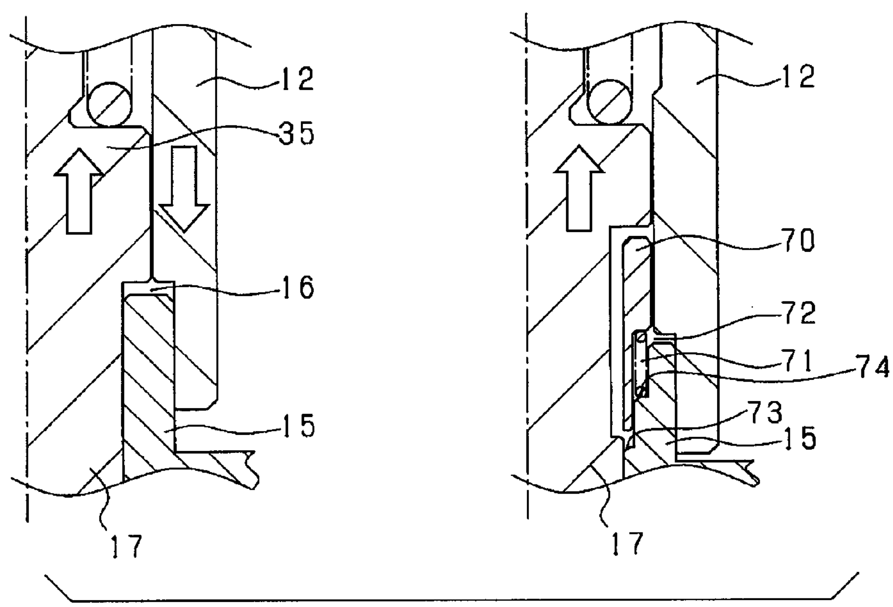

12
35
16
15
17
12
70
72
71
74
73
15
17

FIG. 15

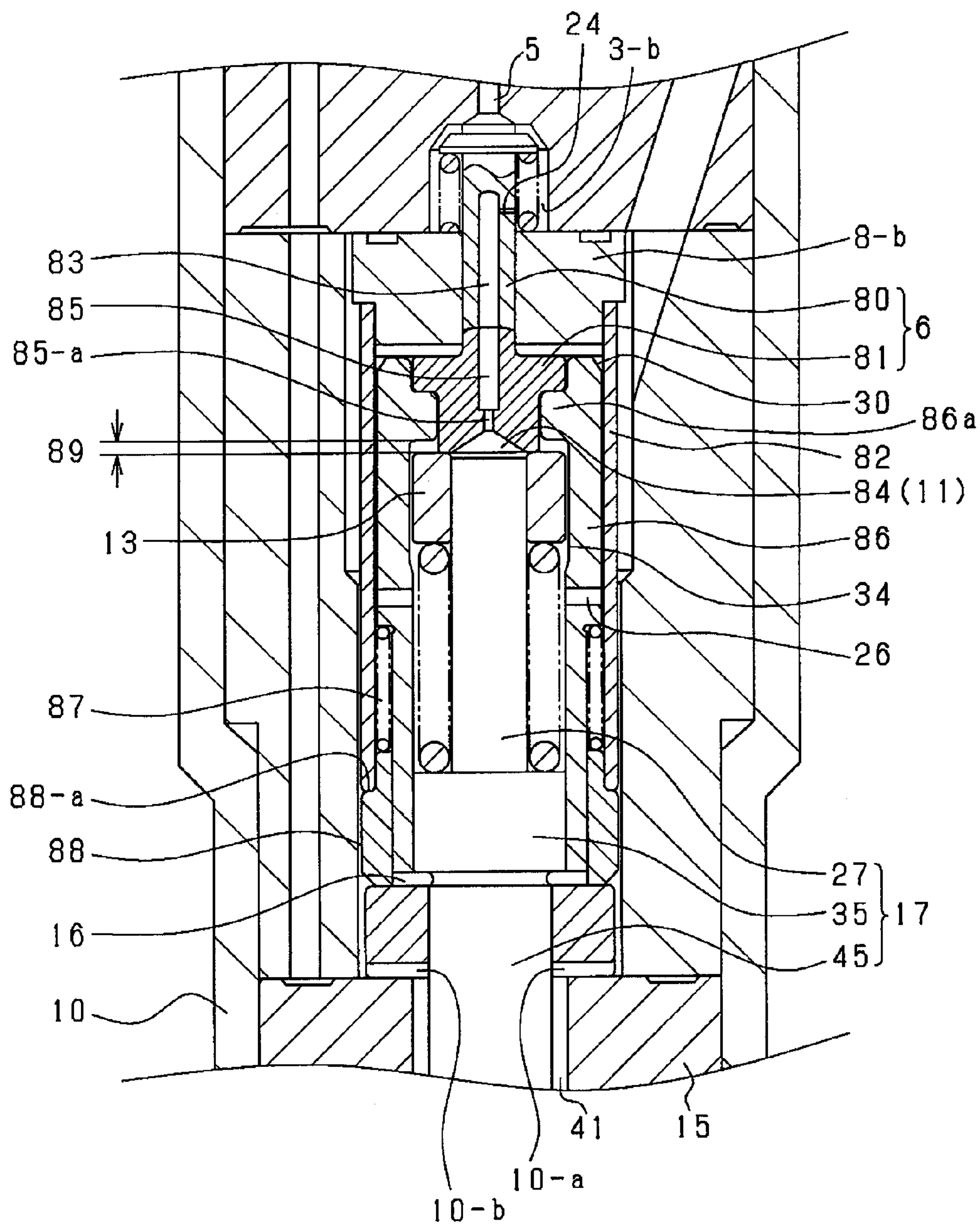

24
5
3-b
8-b
83
80
85
6
85-a
81
30
86a
89
82
84(11)
13
86
34
26
87
88-a
88
27
35
17
16
45
10
41
15
10-a
10-b

FIG. 16

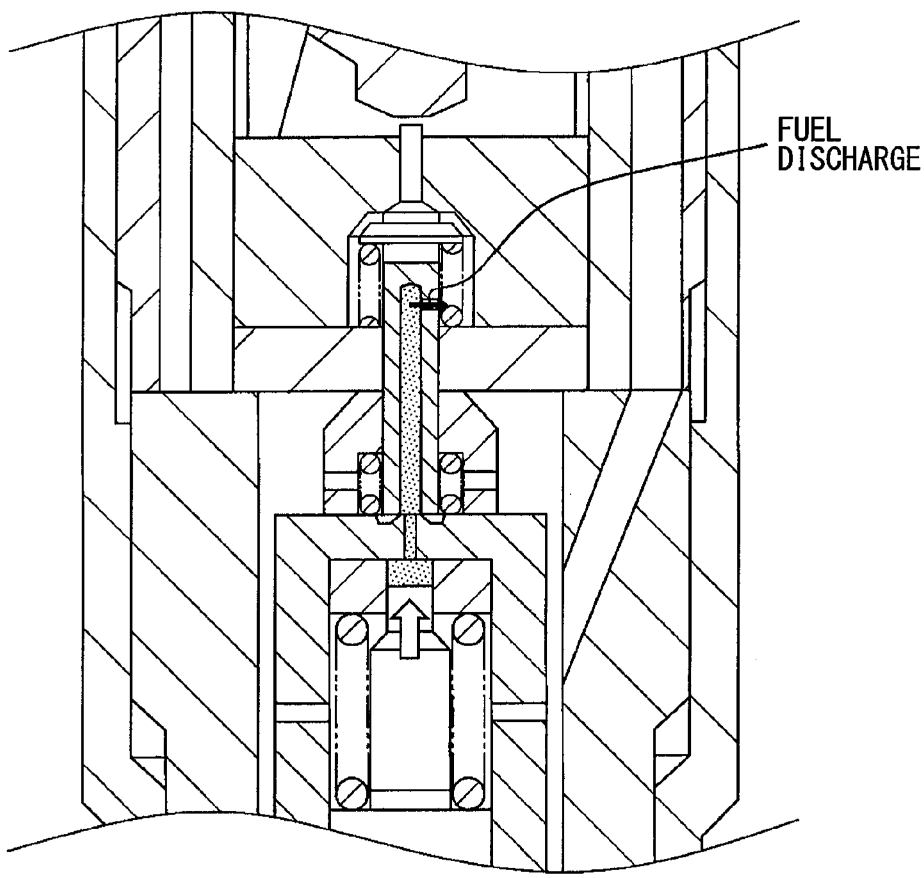


FIG. 17

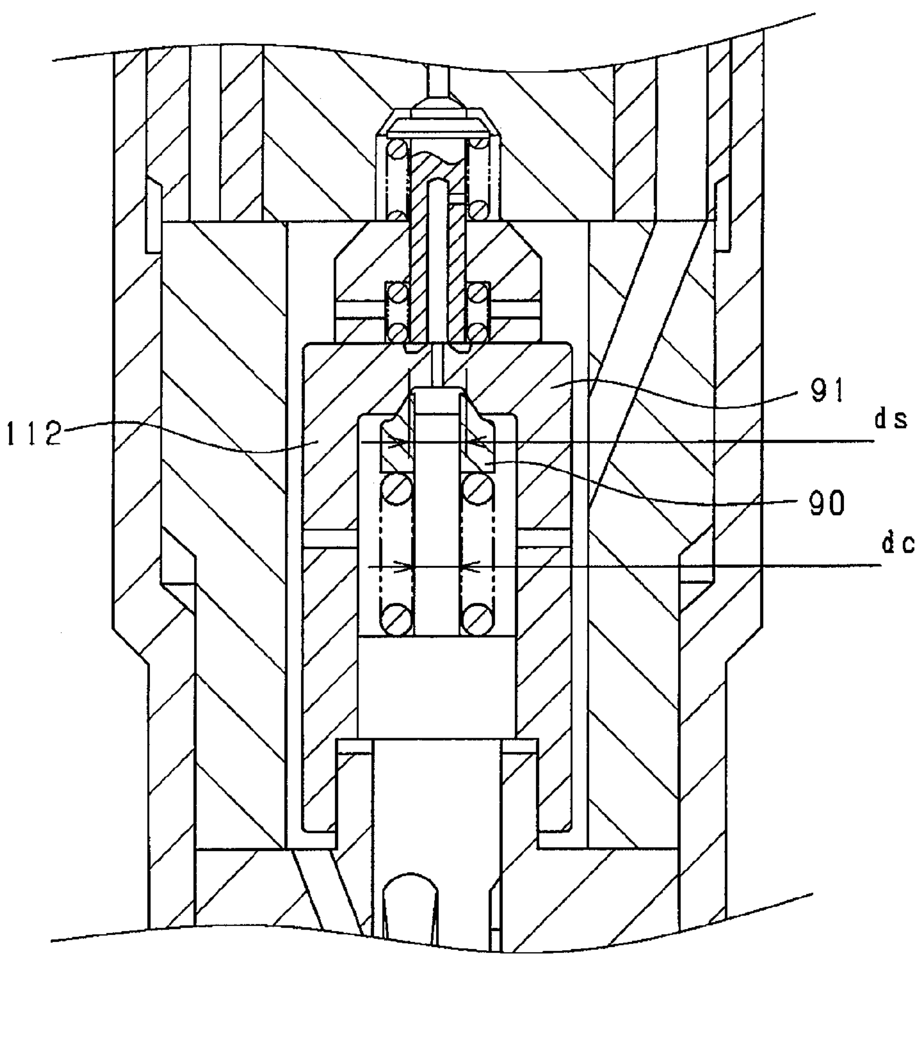


FIG. 18

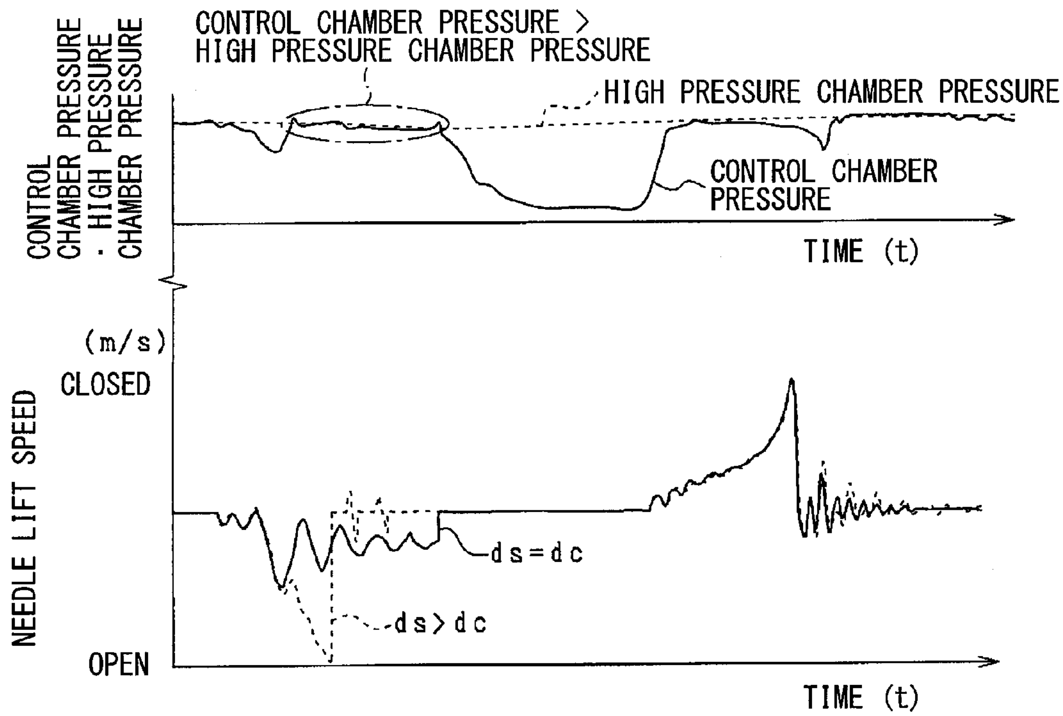

CONTROL CHAMBER PRESSURE > HIGH PRESSURE CHAMBER PRESSURE
HIGH PRESSURE CHAMBER PRESSURE
CONTROL CHAMBER PRESSURE
CONTROL CHAMBER PRESSURE · HIGH PRESSURE CHAMBER PRESSURE
TIME (t)
(m/s)
CLOSED
NEEDLE LIFT SPEED
OPEN
ds=dc
ds>dc
TIME (t)

FIG. 19

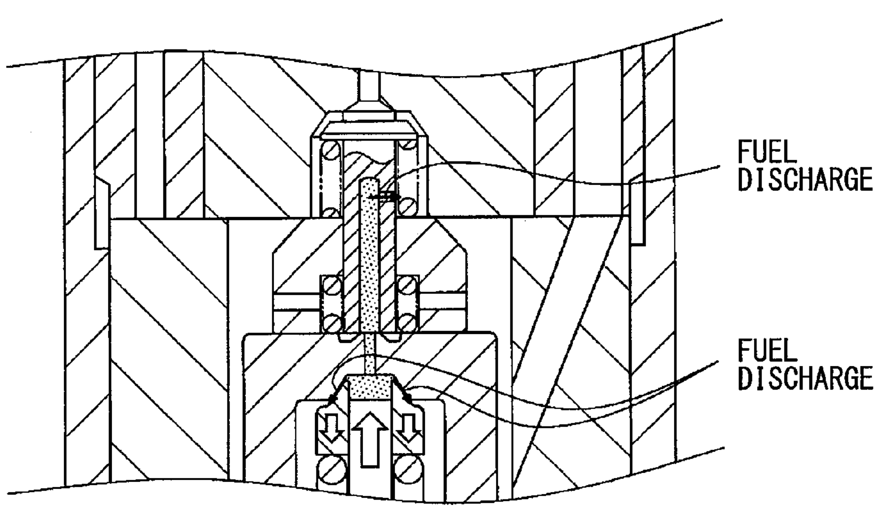

FUEL DISCHARGE
FUEL DISCHARGE

FIG. 20

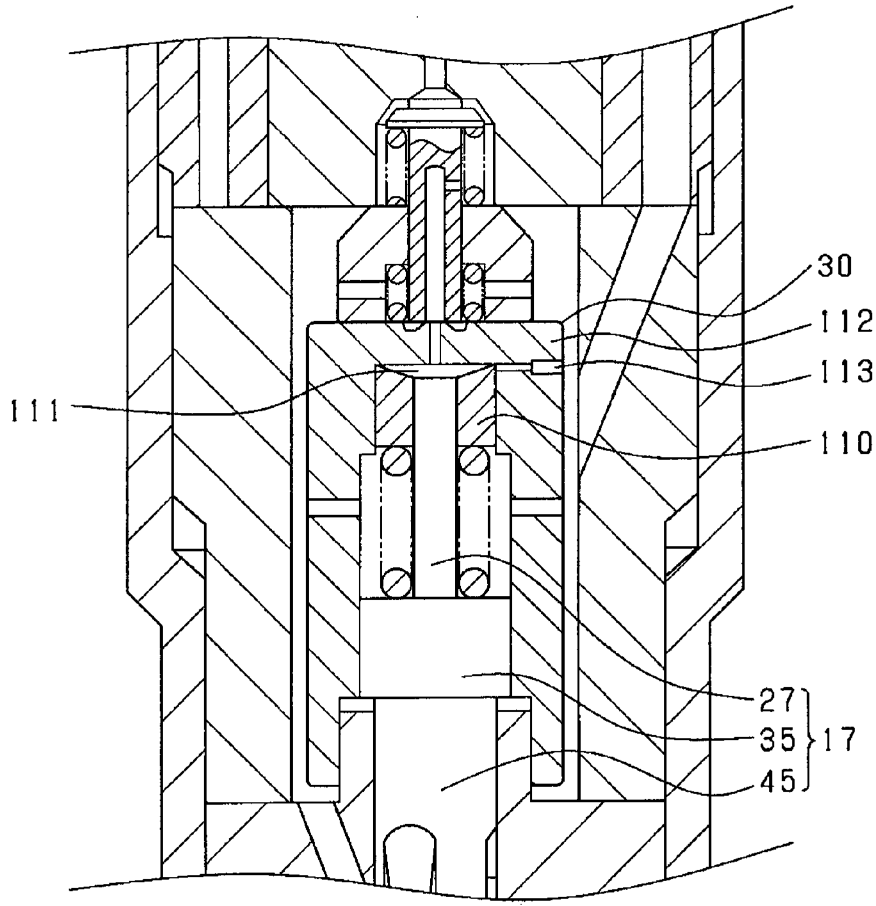


FIG. 21

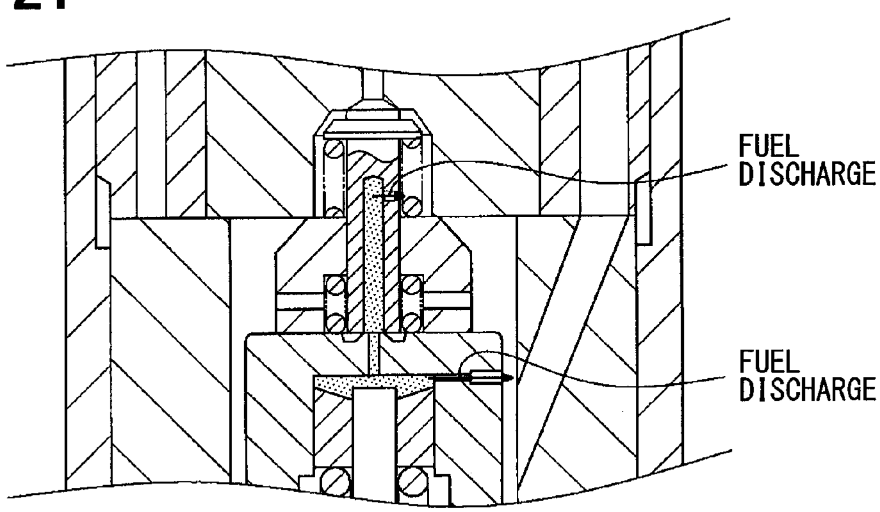


FIG. 22

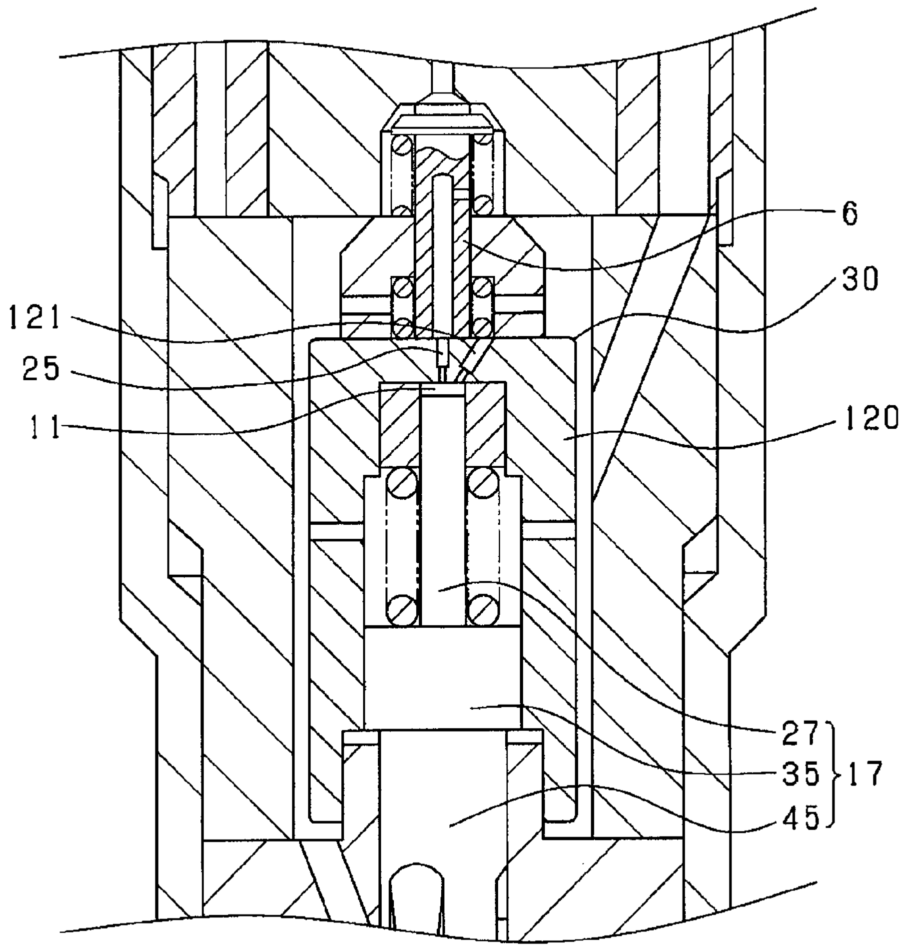


FIG. 23A

LOW SPEED OPENING

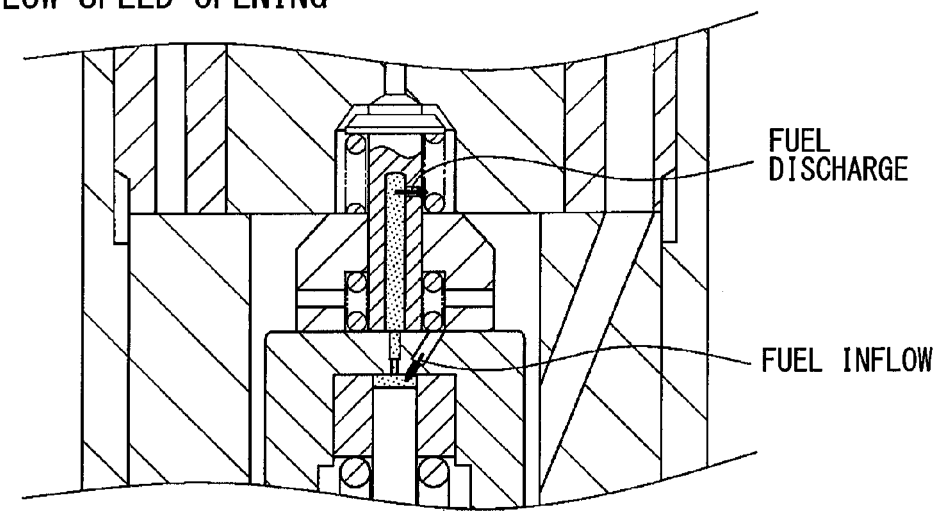


FIG. 23B

HIGH SPEED OPENING

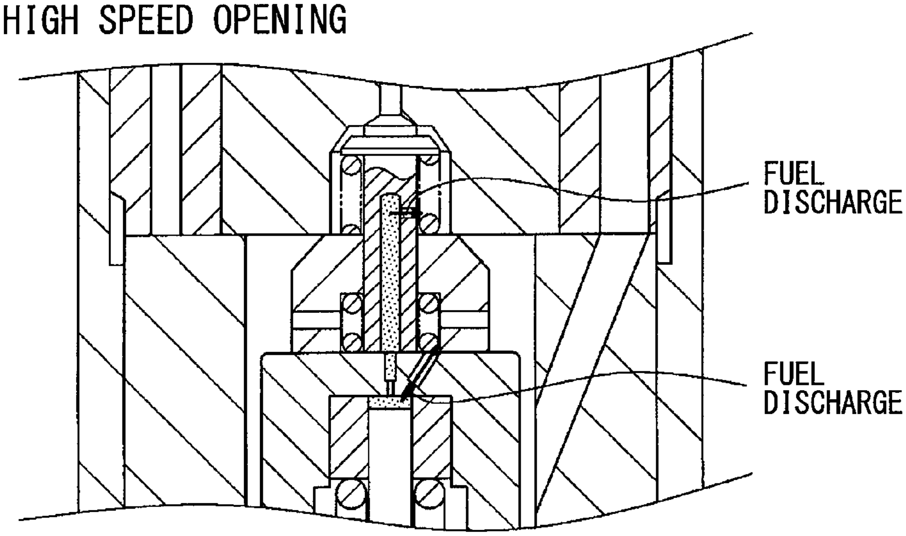


FIG. 24

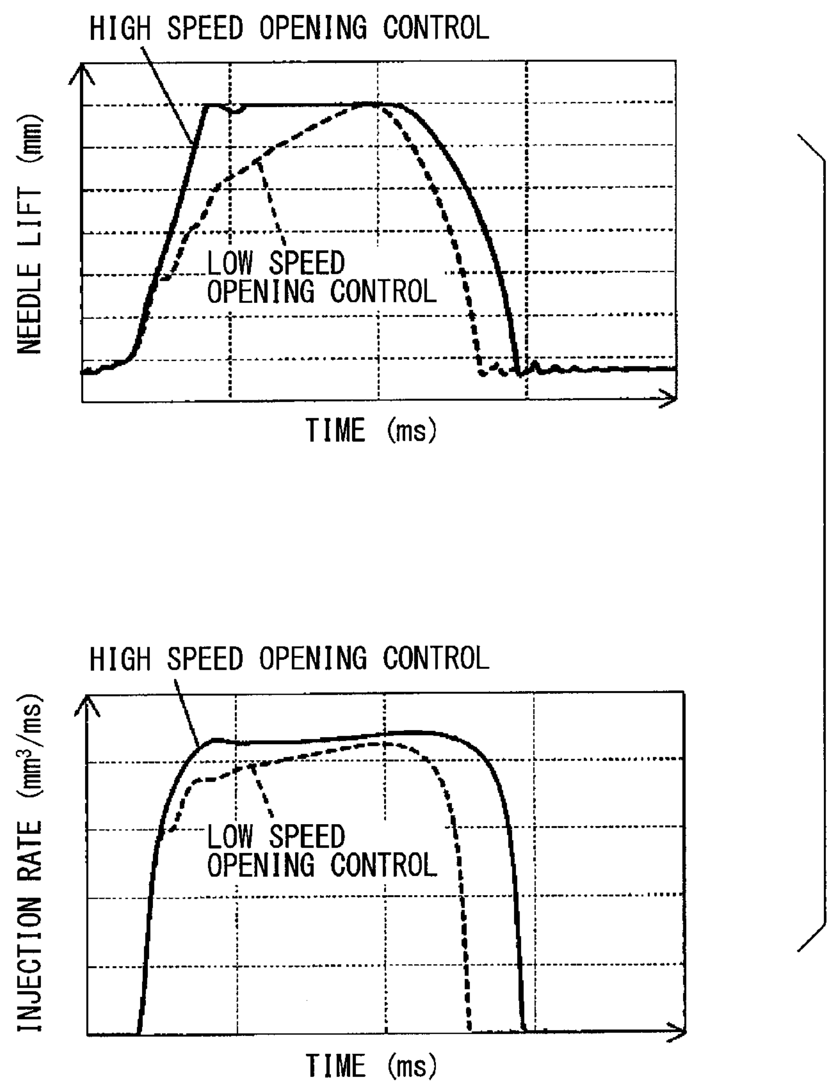

HIGH SPEED OPENING CONTROL
NEEDLE LIFT (mm)
LOW SPEED OPENING CONTROL
TIME (ms)
HIGH SPEED OPENING CONTROL
INJECTION RATE (mm3/ms)
LOW SPEED OPENING CONTROL
TIME (ms)

FIG. 25A

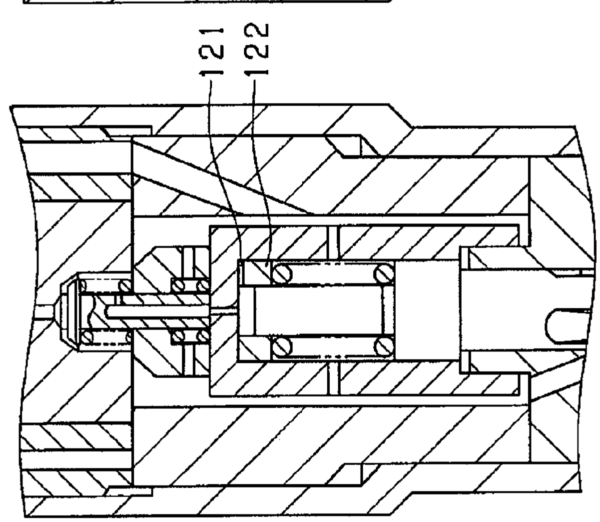


FIG. 25B

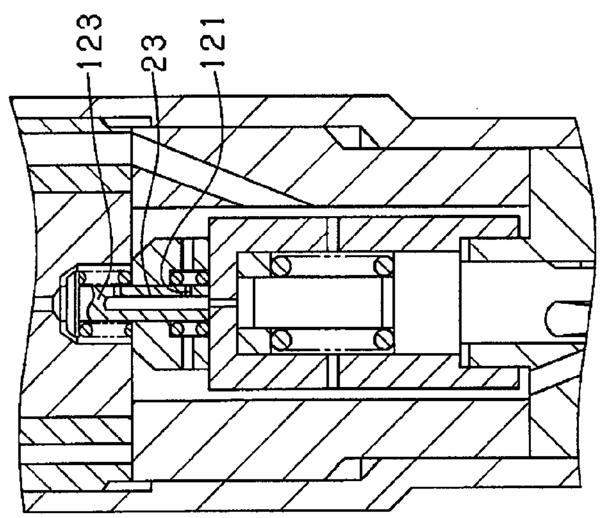


FIG. 25C

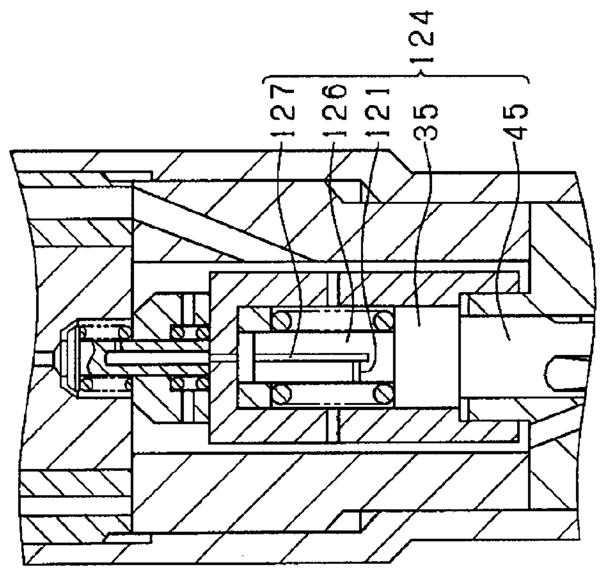


FIG. 26

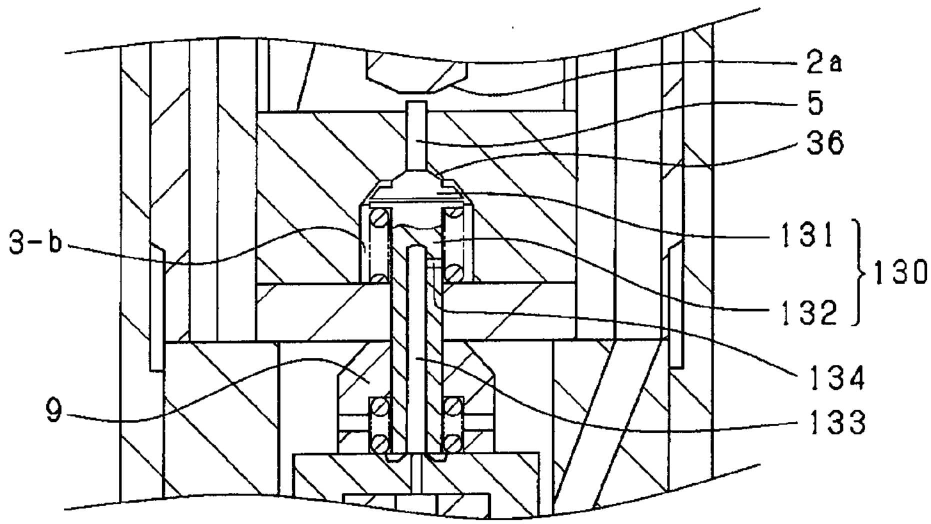


FIG. 27

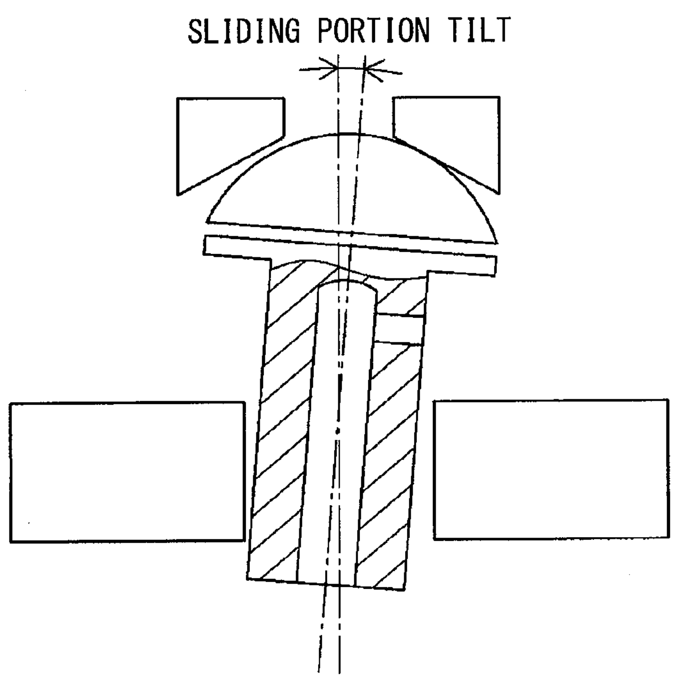


FIG. 28

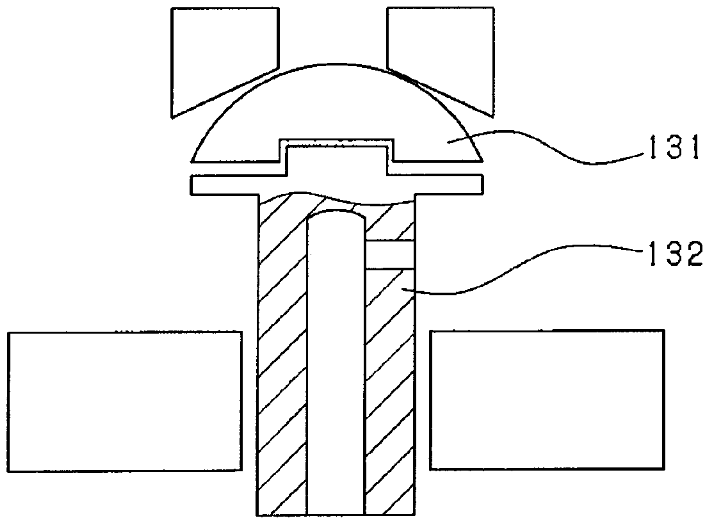


FIG. 29

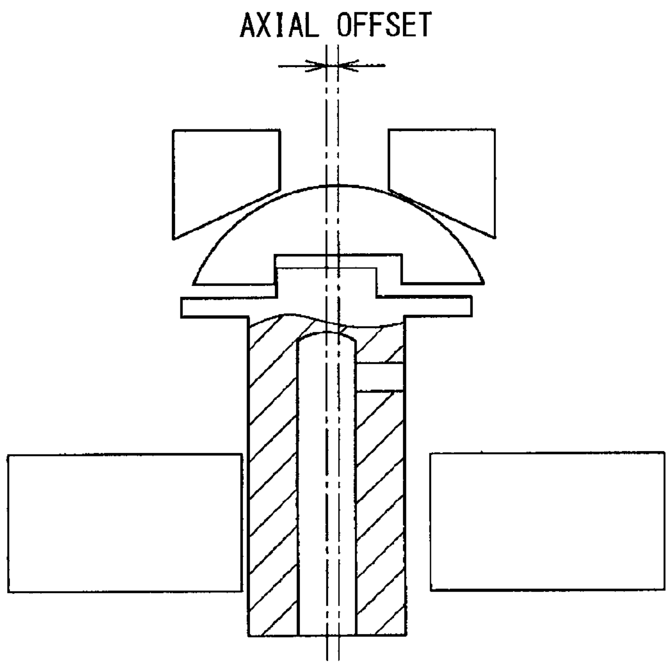


FIG. 30

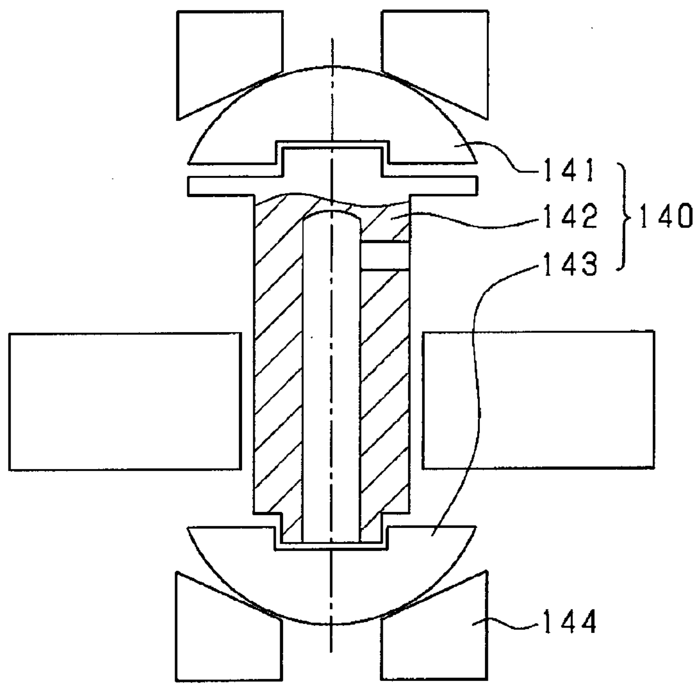


FIG. 31

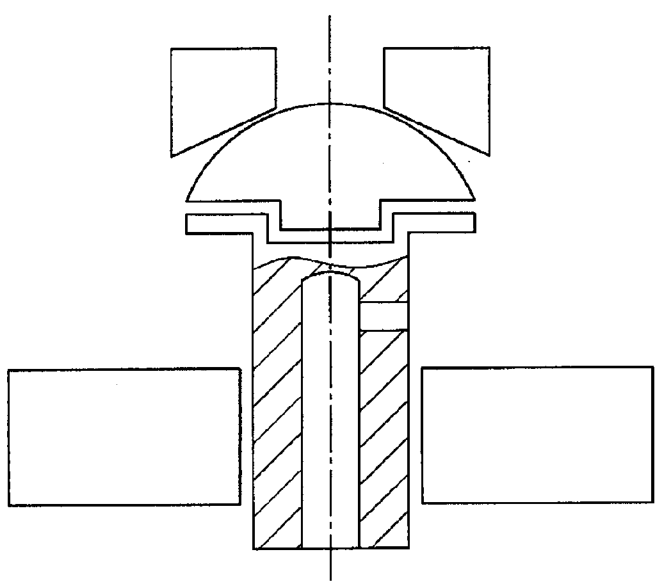


FIG. 32

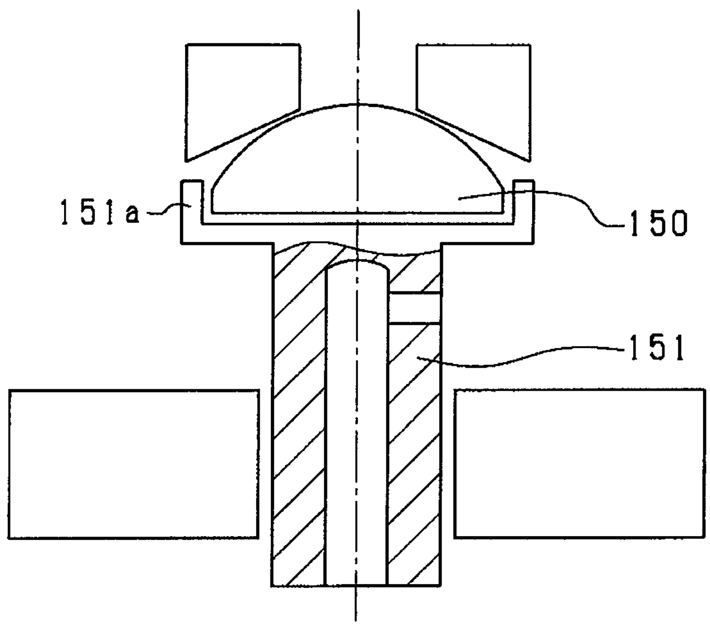


FIG. 33

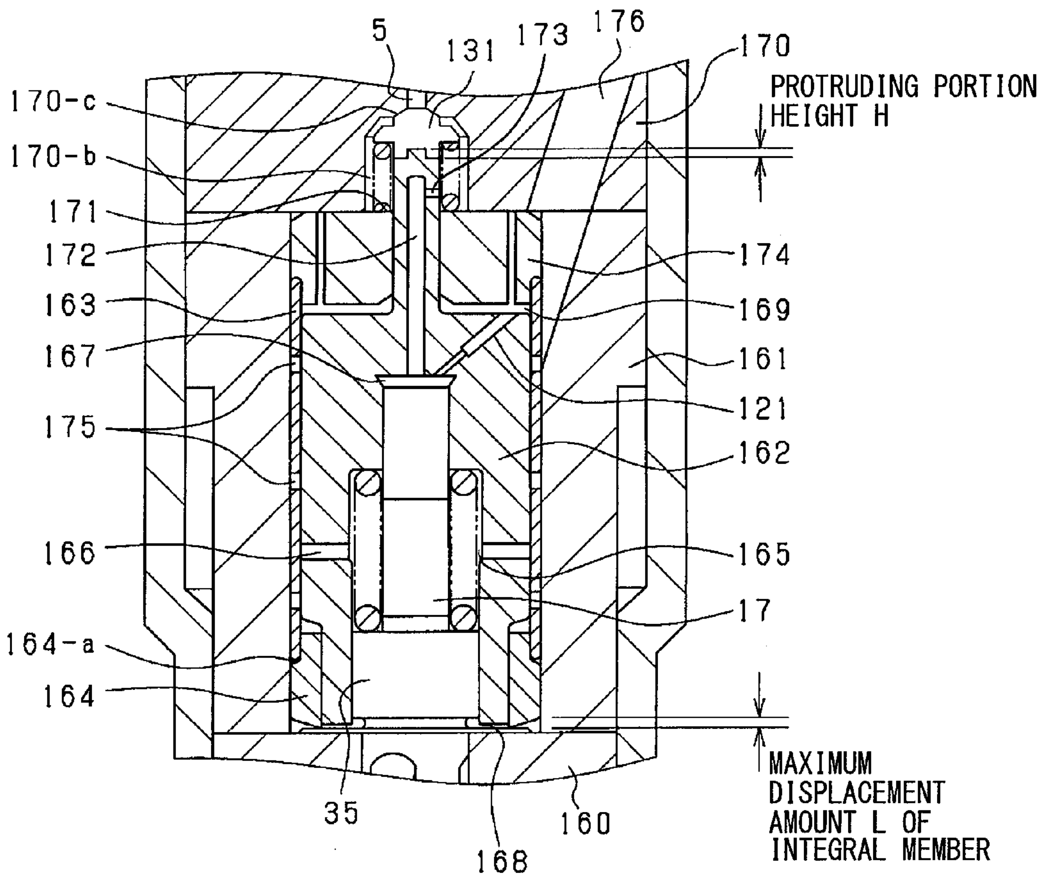
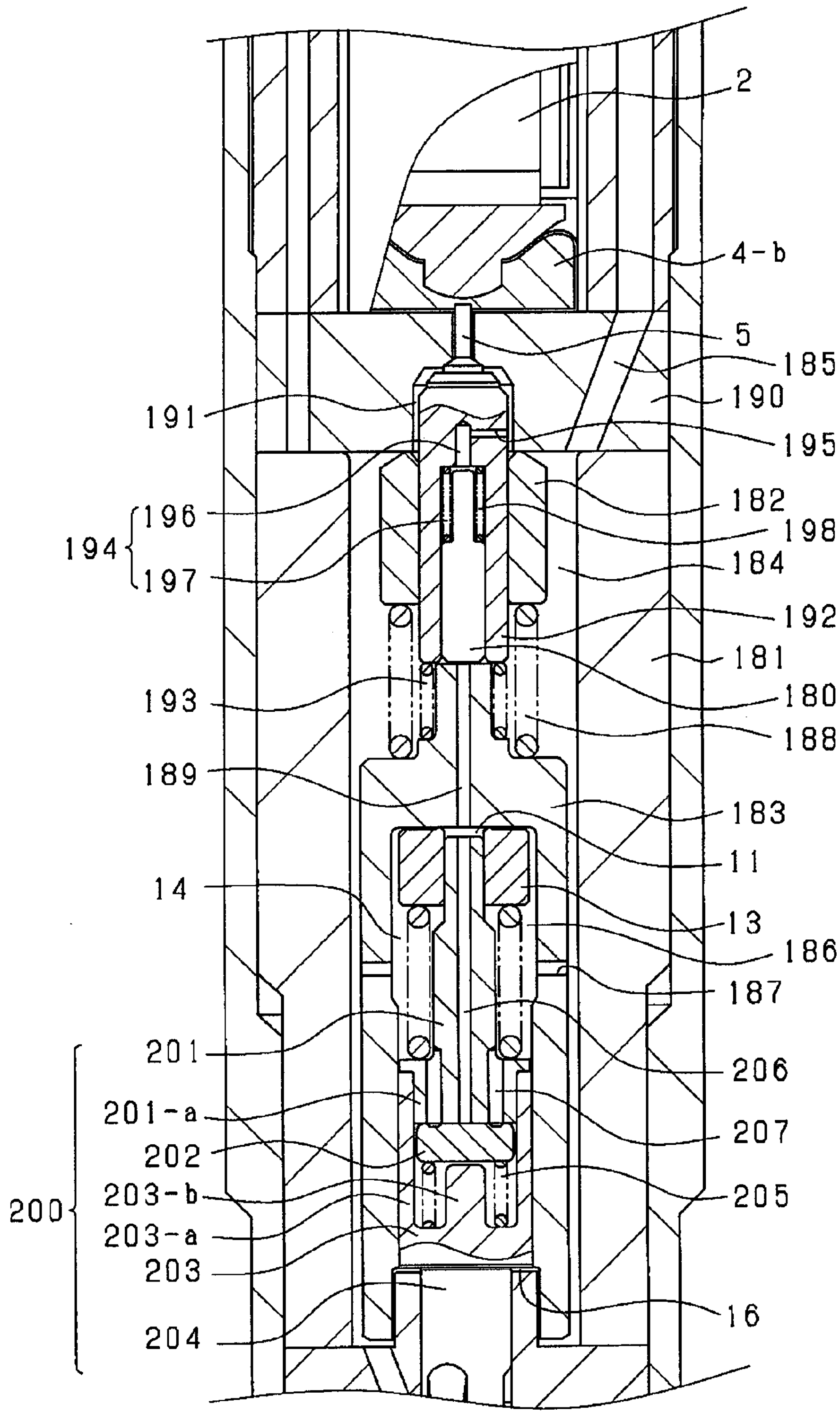

5
131
173
176
170
170-c
170-b
171
172
163
167
175
166
164-a
164
35
168
160
174
169
161
121
162
165
17
PROTRUDING PORTION HEIGHT H
MAXIMUM DISPLACEMENT AMOUNT L OF INTEGRAL MEMBER

FIG. 34


2
4-b
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205
203-a
203
16
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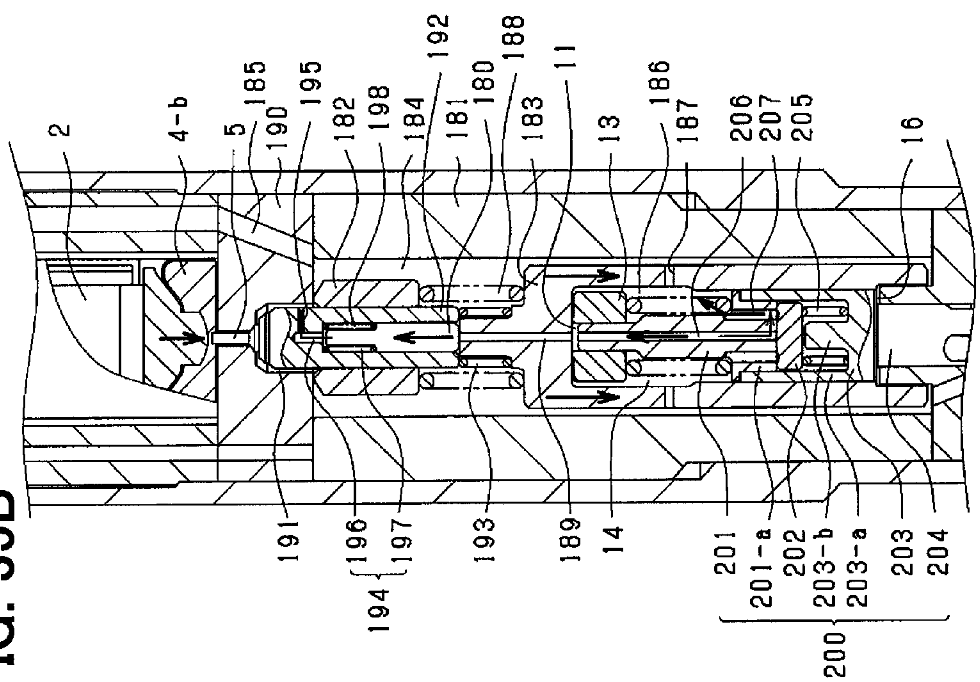

FIG. 35B

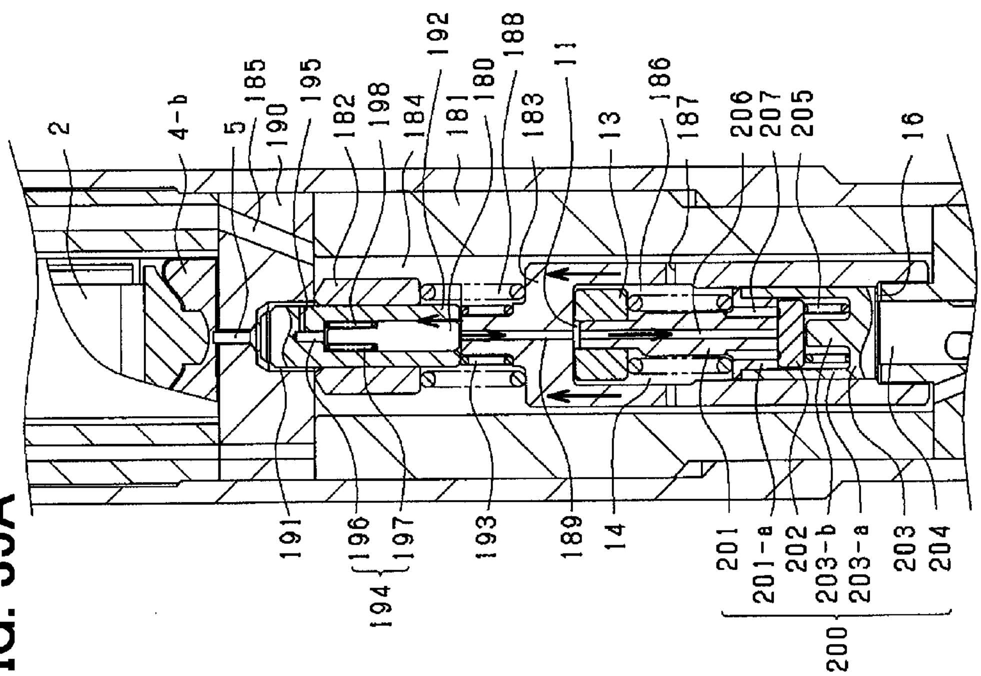

FIG. 35A

FUEL INJECTION VALVE AND FUEL INJECTION VALVE CONTROLLER

CROSS REFERENCE TO RELATED APPLICATION

The present application is based on Japanese Patent Application No. 2015-114556 filed on Jun. 5, 2015 and Japanese Patent Application No. 2016-043629 filed on Mar. 7, 2016, disclosure of which is incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to a fuel injection valve for an internal combustion engine, and a controller that controls a fuel injection valve.

BACKGROUND

Regarding direct acting fuel injection valves for internal combustion engines, it is known that when a piezo stack extends, a needle is pressed and lifted through fuel stored in an oil-tight chamber, and an injection hole of a fuel injection valve is opened. Such a technique is disclosed in, for example, JP 2010-285910.

SUMMARY

However, according to the technique of JP 2010-285910, since a large amount of driving energy may be needed to lift the needle, the fuel injection pressure may be limited.

In view of the above, it is an object of the present disclosure to provide a fuel injection valve with the advantages of direct acting fuel injection valves, while reducing the driving energy needed to lift a needle to allow for a higher fuel injection pressure.

According to the present disclosure, a fuel injection valve comprises a body including a first chamber that supplies fuel at a first pressure, a second chamber that supplies fuel at a second pressure, the second pressure being lower than the first pressure, and an injection hole, a valve chamber member including a valve chamber, the valve chamber being connectable to the first chamber and the second chamber, a control chamber member including a control chamber, the control chamber being connectable to the first chamber, a needle, the needle being pressed by pressure of fuel in the control chamber in a direction that causes fuel injection from the injection hole to stop, an actuator driven to extend and contract, a valve element that blocks the second chamber from the valve chamber and connects the first chamber with the control chamber with each other when the actuator is in a contracted state, and changes position when the actuator extends to connect the second chamber, the valve chamber, and the control chamber with each other and block the first chamber from the control chamber, and a transmission mechanism that transmits a force generated by the actuator extending, which causes the valve element to displace, to the needle as a force in a direction that causes fuel to be injected from the injection hole.

According to the above configuration, the fuel injection valve includes the body provided with the first chamber, the second chamber, and the injection hole. Fuel at the first pressure is supplied at the first chamber. Fuel at the same pressure, which is lower than the first pressure, is supplied at the second chamber. Further, the valve chamber member is provided, and the valve chamber, which is connectable to the first chamber and the second chamber, is provided in the valve chamber member. In addition the control chamber member is provided, and the control chamber which is connectable to the first chamber is disposed. Due to the pressure of the fuel in the control chamber, the needle is pressed in the direction that causes fuel injection from the injection hole to stop.

In addition, the actuator and the valve element are provided in the fuel injection valve. When the actuator is in the contracted state, the valve element blocks the second chamber from the valve chamber, and connects the first chamber with the control chamber. Accordingly, when the actuator is in the contracted state, the fuel at the first pressure stored in the first chamber flows into the control chamber. When the actuator extends, the valve element connects the second chamber with the valve chamber, and blocks the first chamber from the control chamber. Accordingly, when the actuator is extended, the fuel stored in the control chamber flows through the valve chamber and out into the second chamber, and the control chamber depressurizes. For this reason, the force pressing the needle in the direction that causes fuel injection from the injection hole to stop is decreased. In this state, the force generated by the actuator, which causes the valve element to displace, is transmitted by the transmission mechanism to the needle as a force in the direction that causes fuel to be injected from the injection hole. Since the depressurization of the control chamber reduces the force pressing the needle in the direction that causes fuel injection from the injection hole to stop, the amount of force in the direction that causes fuel to be injected from the injection hole transmitted from the transmission mechanism to the needle may be smaller than conventional. As a result, the advantages of direct acting fuel injection valves are gained, while the amount of charge energy needed to cause the needle to lift is reduced, and the fuel injection pressure may be easily increased.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure, together with additional objectives, features and advantages thereof, will be best understood from the following description, the appended claims and the accompanying drawings, in which:

FIG. **1** is a cross sectional view of a fuel injection valve according to a present embodiment;

FIG. **2** is an enlarged cross sectional view around a control chamber of FIG. **1**;

FIG. **3** is a view showing an operation of a fuel injection valve according to a present embodiment;

FIG. **4** is a view showing a relationship between an area of an exposed portion of a needle and an area of a control chamber according to a present embodiment;

FIG. **5** is an enlarged cross sectional view around an oil-tight chamber of FIG. **1**;

FIG. **6** is a view showing differences in drive energy between a present embodiment and a conventional example;

FIG. **7** is a control flowchart performed by an ECU according to a present embodiment;

FIG. **8** is a timing chart showing charge energy, valve lift, control chamber pressure, injection rate and the like according to a present embodiment;

FIG. **9** is a view showing examples of injection rate waveforms according to charge control modes according to a present embodiment;

FIG. **10** is a cross sectional view of a fuel injection valve according to a modified example;

FIG. **11** is a cross sectional view of a fuel injection valve according to a modified example;

FIG. **12** is a view showing an operation of a fuel injection valve according to the modified example of FIG. **11**;

FIG. **13** is a view showing a relationship between areas of components contacting an oil-tight chamber according to the modified example of FIG. **11**;

FIG. **14** is a cross sectional view of a fuel injection valve according to a modified example;

FIG. **15** is a cross sectional view of a fuel injection valve according to a modified example;

FIG. **16** is a view showing an outflow path of fuel in a control chamber according to a present embodiment;

FIG. **17** is a cross sectional view of a fuel injection valve according to a modified example;

FIG. **18** is a view showing effects exhibited by the modified example of FIG. **17**;

FIG. **19** is a view showing an outflow path of fuel in a control chamber according to the modified example of FIG. **17**;

FIG. **20** is a cross sectional view of a fuel injection valve according to a modified example;

FIG. **21** is a view showing an outflow path of fuel in a control chamber according to the modified example of FIG. **20**;

FIG. **22** is a cross sectional view of a fuel injection valve according to a modified example;

FIGS. **23**A and **23**B are views showing an outflow path of fuel in a control chamber according to the modified example of FIG. **22**;

FIG. **24** is a view showing effects exhibited by the modified example of FIG. **22**;

FIGS. **25**A, **25**B, and **25**C are views showing another modification applicable to the modified example of FIG. **22**;

FIG. **26** is a cross sectional view of a fuel injection valve according to a modified example;

FIG. **27** is a view showing effects and another modification applicable to the modified example of FIG. **26**;

FIG. **28** is a view showing another modification applicable to the modified example of FIG. **26**;

FIG. **29** is a view showing effects exhibited by the modified example of FIG. **28**;

FIG. **30** is a view showing another modification applicable to the modified example of FIG. **28**;

FIG. **31** is a view showing another modification applicable to the modified example of FIG. **28**;

FIG. **32** is a view showing another modification applicable to the modified example of FIG. **26**;

FIG. **33** is a cross sectional view of a fuel injection valve according to a modified example;

FIG. **34** is a cross sectional view of a fuel injection valve according to a modified example; and

FIGS. **35**A and **35**B are views showing the operation of a fuel injection valve according to the modified example of FIG. **34**.

DETAILED DESCRIPTION

A fuel injection valve **100** is mounted by being inserted into a cylinder head of an engine, and directly injects fuel supplied from a common rail to the combustion chamber of each cylinder of the engine.

As shown in FIGS. **1** and **2**, this fuel injection valve **100** includes an injector body **1**, a lower body **10**, a nozzle body **15**, a needle **17**, an actuator **2**, and a driver **33**.

The nozzle body **15** is formed as a substantially cylindrical body, and is fixed by a retaining nut **18** to the lower side of the figure of the injector body **1** (i.e., the injection side) through the lower body **10**. A guide bore (needle housing chamber) **43** and an injection hole **19** are formed in the nozzle body **15**. The guide bore **43** slidably houses a cylindrical needle **17**. The injection hole **19** injects fuel when the needle **17** is lifted up. In addition, the injector body **1**, the lower body **10**, and the nozzle body **15** correspond to a main body. In the specification, the nozzle body **15** side of the injector body **1** (the lower side in FIG. **1**) is referred to as a "lower side", and the opposite side (the upper side in FIG. **1**) is referred to as an "upper side".

The guide bore **43** is bored from an upper end surface of the nozzle body **15** to a tip portion of the nozzle body **15**. In addition, the guide bore **43** forms a first high pressure passage **41** from a gap between the inner circumference surface of the guide bore **43** and the outer circumferential surface of the needle **17**. The first high pressure passage **41** guides high pressure fuel to the injection hole **19**. Further, the inner diameter of the nozzle body **15** is enlarged to form a fuel reservoir **42** partway through the guide bore **43**.

A conical seating surface **221** is formed on a tip portion of the first high pressure passage **41** in the inner circumferential surface of the nozzle body **15**, i.e., a tip portion toward the injection hole **19**. A seat surface **331** that seats on the seating surface **221** is formed on a tip portion of the needle **17**. By seating the seat surface **331** on the seating surface **221**, the needle **17** closes and blocks the first high pressure passage **41** from communicating with the injection hole **19**.

Further, a first flow path **44** is formed in the nozzle body **15**. The first flow path **44** connects the first high pressure passage **41** to a high pressure chamber (corresponding to a first chamber) **30** formed in the lower body **10**. A high pressure fuel (corresponding to fuel at a first pressure) guided from a high pressure port **3**, described later, is stored in the high pressure chamber **30**. Accordingly, the high pressure fuel flows into the first high pressure passage **41** through the first flow path **44**. As a result, when the seat surface **331** of the needle **17** separates from the seating surface **221**, the high pressure fuel flowing into the first high pressure passage **41** is injected.

The lower body **10** is formed as a substantially cylindrical body. A portion of the upper end portion (the end portion facing away from the injection hole) of the nozzle body **15** penetrates into the lower body **10**. The high pressure chamber **30** formed in the lower body **10** houses a valve cylinder **9** and a large-diameter piston **12**. A second flow path **29** is connected to the high pressure chamber **30**, and high pressure fuel flowing in from the high pressure port **3** through the second flow path **29** is stored in the high pressure chamber **30**.

A pressing chamber **34** is formed inside the large-diameter piston **12** (corresponding to a particular component included in a transmission mechanism). The pressing chamber **34** houses a portion of the needle **17**. In addition, a first communication passage **26** is disposed in the large-diameter piston **12** such that high pressure fuel flows in from the high pressure chamber **30**. The first communication passage **26** is connected to the pressing chamber **34**.

The needle **17** includes a small-diameter piston portion **27**, a pressing portion **35**, and a circular column portion **45**. A nozzle spring **14** is housed in the pressing chamber **34** disposed in the large-diameter piston **12**. The small-diameter piston portion **27** is inserted inside the nozzle spring **14**. The lower end portion of the small-diameter piston portion **27** is coupled to the upper end portion of the pressing portion **35**, and the lower end portion of the pressing portion **35** is coupled to the circular column portion **45**.

A needle cylinder (corresponding to a control chamber member) **13** is disposed at an upper end side in the pressing chamber **34** (i.e., the upper side of the nozzle spring **14**). The needle cylinder **13** is formed in a substantially cylindrical shape, and a control chamber **11** is formed within the needle cylinder **13**. The upper end portion of the small-diameter piston portion **27** is inserted into the control chamber **11**. The small-diameter piston portion **27** is slidably supported by the needle cylinder **13**. Due to the nozzle spring **14** housed in the pressing chamber **34**, the needle cylinder **13** is biased in an opposite direction from the injection hole **19** (i.e., an upward direction), and the pressing portion **35** is biased toward the injection hole **19**.

An oil-tight chamber **16** is defined by a portion of the needle **17** around the lower end of the pressing portion **35**, a lower portion of the large-diameter piston **12**, and a portion of the nozzle body **15** which protrudes into the lower body **10**.

A substantially cylindrical valve cylinder **9** is housed in the high pressure chamber **30** such that the lower end portion of the valve cylinder **9** is abuttable with the upper end portion of the large-diameter piston **12**. A second communication passage **28** is disposed in the valve cylinder **9** such that the high pressure fuel stored in the high pressure chamber **30** flows into the valve cylinder **9**. A cylinder spring (corresponding to a cylinder biasing member) **20** is disposed within the valve cylinder **9**. Due to the cylinder spring **20**, the valve cylinder **9** is biased in a direction opposite from the injection hole **19** (the up direction in FIG. **1**).

A common orifice **25** is disposed in the large-diameter piston **12** so as to be connectable with the insides of the control chamber **11** and the valve cylinder **9**. For this reason, the high pressure fuel stored in the high pressure chamber **30** is able to flow through the second communication passage **28** and the common orifice **25** into the control chamber **11**.

The injector body **1** is formed in a substantially cylindrical shape, and a valve body (corresponding to a valve chamber member) **8** is housed at a lower portion inside the injector body **1**. A lower end portion of a valve body **8**-*b* of the valve body **8** abuts the upper end portion of the valve cylinder **9** at a valve cylinder seat position **32**. In addition, The upper end portion of the valve body **8**-*b* abuts a lower end portion of a valve body **8**-*a*. A substantially cylindrical valve chamber **3**-*b* is formed inside the valve body **8**-*a*. A hole that communicates the valve chamber **3**-*b* with the inside of the valve cylinder **9** is formed in the valve body **8**-*b*. In addition, a hole in communication with a low pressure chamber **4**-*b* is formed in the valve body **8**-*a*.

A valve spring (corresponding to a valve biasing member) **7** is housed in the valve chamber **3**-*b*. In addition, a portion of a control valve element **6** is inserted into the valve spring **7**. Further, due to the valve spring **7**, the control valve element **6** is biased in an opposite direction from the injection hole **19** (upward direction). The control valve element **6** is slidably supported by the second valve body **8**-*b* and a valve sliding surface **31** of the valve cylinder **9**. The control valve element **6** is housed within the valve body **8** and the valve cylinder **9**.

In addition, a middle chamber **23** is disposed inside the control valve element **6**. The middle chamber **23** is a flow path in which fuel flows. The lower portion of the middle chamber **23** opens at the bottom edge portion of the control valve element **6**, and is in communication with the inside of the valve cylinder **9**. The upper portion of the control valve element **6** is connected to the valve chamber **3**-*b* through an outer orifice **24**. In other words, the control valve element **6** is able to connect the inside of the valve cylinder **9** with the valve chamber **3**-*b* through the middle chamber **23** and the outer orifice **24**. In addition, a gap is formed between the lower end portion of the control valve element **6** and the upper end portion of the large-diameter piston **12**. Accordingly, the high pressure chamber **30** is connected to the control chamber **11** through the second communication passage **28**.

A drive transmission pin **5** is inserted into the hole formed in the valve body **8**-*a*. A gap is formed between the drive transmission pin **5** and the hole formed in the valve body **8**-*a*. The lower end portion of the drive transmission pin **5** abuts the upper end portion of the control valve element **6**. The upper end portion of the drive transmission pin **5** protrudes out from the valve body **8**-*a*.

The actuator **2** is housed inside the injector body **1**. The lower end portion of the actuator **2** is connected to a flange portion **2***a*. The flange portion **2***a* is abuttable with the drive transmission pin **5**. According to the present embodiment, the actuator **2** is formed by stacking a great number of piezoelectric elements in a stack body (piezo elements).

Due to this configuration, when the actuator **2** is driven (extended), the flange portion **2***a* connect to the actuator **2** abuts the drive transmission pin **5**, and due to this, the control valve element **6** is moved toward the needle **17**.

The low pressure chamber (corresponding to a second chamber) **4**-*b* is formed between the valve body **8**-*a* and the flange portion **2***a* in the injector body **1**. The low pressure chamber **4**-*b* is in communication with a low pressure passage **4**. For this reason, low pressure fuel (corresponding to fuel at a second pressure) stored in the low pressure chamber **4**-*b* flow out from the low pressure chamber **4**-*b* into the low pressure passage **4**, and ultimately is discharged into the fuel tank.

The driver **33** includes an ECU (electronic control unit) **33**-*a* and an EDU (electronic driving unit) **33**-*b*. The ECU **33**-*a* is primarily formed of a microcomputer (microprocessor) including a CPU, ROM, RAM, rewritable non-volatile memory such as flash memory, and an I/O interface.

The ECU **33**-*a* performs control programs stored on the ROM or the flash memory based on signals received from a superior ECU. As a result, a variety of control processes for controlling the fuel injection valve **100** are performed. For example, the ECU **33**-*a* outputs a control signal to the EDU-**33***b* to control the extension and contraction of the actuator **2**.

The EDU **33**-*b* includes a high voltage generation circuit that generates a high voltage which is applied to the actuator **2**. In addition, a plurality of switching elements included in the EDU **33**-*b* are switched on and off based on injection signals, or control signals, from the ECU **33**-*a* to control a power supply state to the actuator **2**. As a result, the EDU **33**-*b* controls the driving state of the actuator **2** based on the control signals output by the ECU **33**-*a*.

According to conventional direct acting fuel injection valves, a large amount of driving energy may be needed to lift the needle **17**, and the fuel injection pressure may be limited. In view of this, according to the present embodiment, the oil-tight chamber **16** is disposed between the lower end portion of the large-diameter piston **12**, the nozzle body **15**, and the needle **17**. In addition, the control chamber **11** is disposed inside the large-diameter piston **12**. In other words, the configuration of the fuel injection valve **100** is based on direct acting fuel injection valves, and at the same time, is also based on hydraulic-servo type fuel injection valves. The operation effects of this are shown below.

FIG. **3** shows the operation of each component when the needle **17** is open and closed. When the needle **17** is closed, the actuator **2** is not extended. Accordingly, a gap exists between the flange portion **2***a* connected to the actuator **2** and the drive transmission pin **5**. In this state, a gap is formed between the large-diameter piston **12** and the control valve element **6**. Accordingly, the high pressure fuel from the high pressure chamber **30** flows through the second communication passage **28** and flows into the control chamber **11** and the valve chamber **3**-*b*. Due to this, the fuel pressure in the valve chamber **3**-*b* increases, and a force is generated in the valve chamber **3**-*b* that presses the control valve element **6** toward the actuator **2**.

This force that presses the control valve element **6** toward the actuator **2** is greater than a force of the low pressure fuel stored in the low pressure chamber **4**-*b* pressing the control valve element **6** toward the injection hole **19**. Accordingly, the control valve element **6** is seated on a seat portion **36** of the valve chamber **3**-*b*. Due to this, it is possible to close a gap between the control valve element **6** and the seat portion **36** which occurs when the control valve element **6** is not seated on the seat portion **36**. At this time, the biasing force of the valve spring **7**, which biases the control valve element **6** toward the actuator **2** (in the upward direction), is also applied to the control valve element **6**. Accordingly, the responsiveness of seating the control valve element **6** on the seat portion **36** may be improved.

In other words, the fuel pressure in the valve chamber **3**-*b* and the control chamber **11** becomes equal to the pressure of the high pressure fuel in the high pressure chamber **30**. For example, regarding the control chamber **11** shown in FIG. **4**, the section of the small-diameter piston portion **27** which receives the pressure of the fuel in the control chamber **11** has a projection area (control chamber area) Sctrl when projected in the movement direction of the needle **17**. In addition, the portion of the needle **17** exposed to the injection hole **19** has a projection area (exposed area) Sseat when projected in the movement direction of the needle **17**.

As a comparative example, it is assumed that the projection area Sctrl is set to be greater than the projection area Sseat. In this case, the portion of the needle **17** having applied the pressure of the high pressure fuel from below has a projection area, when projected in the movement direction of the needle **17**, which is greater than the projection area Sctrl of the portion of the needle **17** having applied the pressure of the high pressure fuel from above. For this reason, when the pressure of the fuel in the control chamber **11** decreases, the force pressing the needle **17** toward the actuator **2** becomes greater than the force pressing the needle **17** toward the injection hole **19**. As a result, there is a concern that the needle **17** may move, in a direction that causes fuel to be injected from the injection hole **19**, without the force from the actuator **2** being transmitted through the fuel in the oil-tight chamber **16**.

As a countermeasure to this, according to the present embodiment, the control chamber area Sctrl is set to be smaller than the exposed area Sseat, as shown in FIG. **4**. Due to this, it is possible to prevent the needle **17** from moving in a direction that causes fuel to be injected from the injection hole **19**, until the force from the actuator **2** is transmitted through the fuel in the oil-tight chamber **16**.

Returning to FIG. **3**, due to the fuel pressure in the control chamber **11** increasing, the needle **17** is pressed toward the injection hole **19**, and the seat surface **331** of the needle **17** seats on the seating surface **221**. Along with this, the pressing portion **35** of the needle **17** presses on a portion of the oil-tight chamber **16**. Due to the pressing portion **35** pressing on the fuel in the oil-tight chamber **16**, the pressure of the fuel in the oil-tight chamber **16** is applied to the portion of the large-diameter piston **12** facing the oil-tight chamber **16**. Accordingly, the large-diameter piston **12** is moved toward the actuator **2** (in the upward direction).

When opening the needle **17**, the EDU **33**-*b* supplies a driving voltage to the actuator **2** based on driving signals from the ECU **33**-*a*. Due to this driving voltage, the actuator **2** extends. Accordingly, the flange portion **2***a* connected to the actuator **2** contacts the drive transmission pin **5**, and the drive transmission pin **5** causes the control valve element **6** to contact the large-diameter piston **12**. Since the control valve element **6** contacts the large-diameter piston **12**, the connection between the control chamber **11** and the high pressure chamber **30** through the second communication passage **28** is cut off, and the control chamber **11** is connected to the middle chamber **23** disposed in the control valve element **6**.

Meanwhile, since the drive transmission pin **5** is pushing into the control valve element **6**, the control valve element **6** separates from the seat portion **36** of the valve chamber **3**-*b*, and a gap exists between the seat portion **36** and the control valve element **6**. Due to this, the middle chamber **23** in the control valve element **6**, which is connected to the control chamber **11**, is in communication with the low pressure chamber **4**-*b* through the middle chamber **23**. Accordingly, the high pressure fuel that flowed from the high pressure chamber **30** into the valve chamber **3**-*b* when the actuator **2** was non-driven now flows out into the low pressure chamber **4**-*b*. For this reason, the fuel pressure inside the valve chamber **3**-*b* decreases, and the high pressure fuel stored in the control chamber **11** flows through the valve chamber **3**-*b* and into the low pressure chamber **4**-*b*. Accordingly, the fuel pressure inside the control chamber **11** decreases, and the pressure force exerted by the pressing portion **35** on the needle **17** toward the injection hole **19** decreases.

However, since the control chamber area Sctrl is smaller than the exposed area Sseat, even if the amount of force applied by the control chamber **11** on the needle **17** toward the injection hole **19** decreases as a result of the pressure reduction in the control chamber **11**, this force is still greater than the amount of force urging the needle **17** to move in a direction that causes fuel to be injected from the injection hole **19**. Accordingly, although the amount of force applied on the needle **17** toward the injection hole **19** decreases, the seat surface **331** of the needle **17** remains seated on the seating surface **231**.

In this state, the control valve element **6** presses the large-diameter piston **12** toward the injection hole **19** as the actuator **2** extends. Accordingly, the fuel inside the oil-tight chamber **16**, which is in contact with the large-diameter piston **12**, is compressed. Then, the pressure of the fuel in the oil-tight chamber **16** is applied to the portion of the pressing portion **35** facing the oil-tight chamber **16**, and the pressing portion **35** is moved toward the actuator **2** (upward direction). Accordingly, the needle **17** starts to lift (rise up).

As shown in FIG. **5**, according to the present embodiment, an area Slarge in which the large-diameter piston **12** presses against the fuel in the oil-tight chamber **16** is set to be greater than an area Ssmall in which the fuel in the oil-tight chamber **16** presses against the pressing portion **35**. Due to this, when the large-diameter piston **12** presses the oil-tight chamber **16** by an amount of movement, in comparison, the pressing portion **35** is moved toward the actuator **2** by a greater amount of movement. Consequently, even if the actuator **2** only extends by a small amount, the needle **17** may be sufficiently moved in a direction that causes fuel to be injected from the injection hole **19**.

In this regard, according to the present embodiment, a direct acting force is generated on the needle **17** toward a direction that causes fuel to be injected from the injection hole **19**. This direct acting force is generated while a force, which presses the needle **17** in a direction that causes fuel injection from the injection hole **19** to be stopped, is decreased. For this reason, as shown in FIG. **6**, the energy needed to open the needle **17** is decreased as compared to a conventional direct acting fuel injection valve.

The ECU **33**-*a* includes a plurality of charge control modes for charging the actuator **2**. According to the present embodiment, these charge control modes include a direct acting assist mode (corresponding to a first charge control mode) and a hydraulic servo mode (corresponding to a second charge control mode) which have different charge energy timings. The charge energy timing is defined as when reaching a required amount of charge energy from the start of charging the actuator **2** until the needle **17** is moved in a direction that causes fuel to be injected from the injection hole **19**.

Next, the control details of an injection rate waveform control process of the fuel injection valve **100** performed by the ECU **33**-*a* will be explained with reference to FIG. **7**. The injection rate waveform control process of the fuel injection valve **100** shown in FIG. **7** is repeatedly performed by the ECU **33**-*a* with a fixed frequency while the ECU **33**-*a* is powered on.

When the present control process begins, first at step S**100**, injection signals and driving conditions are received from a superior ECU and read. The injection signals include signals designating a fuel injection amount, an injection timing, an injection period, and an injection rate. These values depend on the driving conditions of the vehicle at the time. Specifically, the ECU **33**-*a* obtains, from a superior ECU, an optimum fuel injection amount and fuel injection timing based on engine operation information such as engine rotation speed or accelerator angle. In addition, the fuel injection rate (valve opening degree) and the injection period are determined according to the injection amount and the fuel pressure in the common rail. The ECU **33**-*a* receives all of these values from the superior ECU.

At step S**110**, it is determined whether the direct acting assist mode should be implemented, according to the injection signals received at step S**100**. Specifically, when the injection signals designate a (high rectangle) injection rate having a rising rate greater than a predetermined value, the direct acting assist mode is implemented. Conversely, when the injection signals designate a (low rectangle) injection rate having a rising rate lower than a predetermined value, the hydraulic servo mode is implemented.

When it is determined that the direct acting assist mode should be implemented (S**110**: YES), the process continues to step S**120**, the direct acting assist mode is implemented, and the present control process ends. When it is determined that the direct acting assist mode should not be implemented (S**110**: NO), the process continues to step S**130**, the hydraulic servo mode is implemented, and the present control process ends.

Next, the operations of the direct acting assist mode and the hydraulic servo mode will be explained with reference to FIG. **8**. In addition, here, the charging period of the actuator **2** is fixed for both the direct acting assist mode and the hydraulic servo mode.

In FIG. **8**, "injection command" uses high/low to represent whether injection signals, which command that a fuel injection be performed, are received. "Charge energy" refers to the amount of energy charged to the actuator **2**. "Valve lift" refers to how much the control valve element **6** has lifted. "Control chamber pressure" is the fuel pressure in the control chamber **11**. "Needle lift" refer to how much the needle **17** has lifted. "Injection rate" refers to the injection rate of fuel injected from the fuel injection valve **100**.

According to the present embodiment, the needle **17** begins to move in a direction that causes fuel to be injected from the injection hole **19** (i.e., rise up) when two conditions are satisfied: when the charge energy accumulated in the actuator **2** reaches a needle opening energy Endl, and when the fuel pressure in the control chamber **11** falls to a return pressure.

First, the direct acting assist mode will be explained. When the injection command switches from low to high (refer to time t**1**), the actuator **2** begins to be charged. When the charge energy to the actuator **2** reaches a valve opening energy (corresponding to a connection operation energy) Evlv, the control valve element **6** begins to descend due to the actuator **2** extending (refer to time t**2**). Then, when the control valve element **6** completes the descent, the middle chamber **23** disposed in the control valve element **6** is connected to the control chamber **11**, and the connection between the control chamber **11** and the high pressure chamber **30** is cut off (refer to time t**3**). Due to this, the high pressure fuel stored in the control chamber **11** is discharged through the middle chamber **23** and the valve chamber **3**-*b* into the low pressure chamber **4**-*b*, and the pressure in the control chamber **11** begins to decrease. Then, after time passes, the pressure in the control chamber **11** decreases to reach a return pressure (corresponding to a predetermined pressure) and finishes decreasing (refer to time t**4**).

Next, when the charge energy to the actuator **2** reaches the needle opening energy Endl (refer to time t**5**), the needle **17** moves in a direction that causes fuel to be injected from the injection hole **19** (i.e., rise up). At this time, since the charge period has not finished, the charge energy to the actuator **2** continues to increase, and as a result, the rate of rise of the needle **17** also increases. FIG. **9** shows a specific example of the degree of rectangularity in the direct acting assist mode. An injection during the direct acting assist mode may be applied to, for example, a main injection.

Next, the hydraulic servo mode will be explained. When the injection command changes from low to high (refer to time t**1**), the actuator **2** begins to be charged. Then, when the charge energy to the actuator **2** reaches the valve opening energy Evlv, the control valve element **6** begins to descend due to the actuator **2** extending (refer to time t**6**). Then, when the control valve element **6** completes the descent, the pressure in the control chamber **11** begins to decrease (refer to time t**7**).

After the charge energy to the actuator **2** reaches the valve opening energy Evlv and before the charge period ends, the charge rate is increased such that the charge energy to the actuator **2** reaches the needle opening energy Endl (refer to time t**6** to t**8**). At this time, even if the energy to the actuator **2** reaches the needle opening energy Endl, the fuel pressure of the control chamber **11** has not fallen to the return pressure, and therefore the needle **17** has not begun to rise (refer to time t**8**). Then, when the fuel pressure of the control chamber **11** completes falling to the return pressure, the needle **17** begins to rise (refer to time t**9**). At this time, the final charge energy of the actuator **2** charged in the end is less than the final charge energy in the direct acting assist mode. Accordingly, the rate of rise of the needle **17** is slower than in the direct acting assist mode, and the rectangularity of the injection rate is also lower. FIG. **9** shows a specific example of the degree of rectangularity in the hydraulic servo mode. An injection during the hydraulic servo mode may be applied to, for example, a pilot injection.

In the direct acting assist mode, a valve opening energy timing (corresponding to a connection operation energy timing), which is when the charge energy to the actuator **2** reaches the valve opening energy Evlv, is set to be earlier than the valve opening energy timing in the hydraulic servo mode. Since the depressurization rate in the control chamber **11** is the same for either mode, the fuel pressure in the control chamber **11** completes depressurization at an earlier timing in the direct acting assist mode (refer to time t**4**) than when the fuel pressure in the control chamber **11** completes depressurization in the hydraulic servo mode (refer to time t**9**).

Due to the above configuration, the fuel injection valve **100** and the ECU **33**-*a* of the present embodiment exhibits the following effects.

When the actuator **2** is in an extended state, the fuel stored in the control chamber **11** is expelled through the control valve element **6** into the low pressure chamber **4**-*b*, and the pressure control chamber **11** depressurizes. For this reason, the amount of force pressing the needle **17** in a direction that stops fuel injection from the injection hole **19** decreases. In this state, as the actuator **2** extends, a displacement force is generated on the control valve element **6**. Due to the large-diameter piston **12**, this displacement force is transmitted as a force that urges the needle **17** in a direction that causes fuel to be injected from the injection hole **19**.

Accordingly, since the amount of force pressing the needle **17** in a direction that stops fuel injection from the injection hole **19** decreases due to the depressurization of the control chamber **11**, the force transmitted from the large-diameter piston **12** to the needle **17** in a direction that causes fuel to be injected from the injection hole **19** may be smaller than as conventional. As a result, the advantages of direct acting fuel injection valves are gained, while the amount of charge energy to the actuator **2** needed to cause the needle **17** to lift is reduced, and the fuel injection pressure may be easily increased.

The section of the small-diameter piston portion **27** of the needle **17** which receives the pressure of the fuel in the control chamber **11** has a projection area Sctrl when projected in the movement direction of the needle **17**. Further, the portion of the needle **17** exposed to the injection hole **19** has a projection area Sseat when projected in the movement direction of the needle **17**. Here, Sctrl is set to be smaller than Sseat. For this reason, even if the pressure of the fuel in the control chamber **11** decreases, a force is applied to the needle **17** in a direction that stops fuel injection from the injection hole **19**, and the needle **17** may be suppressed from rising.

The control valve element **6** is biased toward the low pressure chamber **4**-*b* by the valve spring **7**. Accordingly, by biasing the control valve element **6** toward the low pressure chamber **4**-*b*, it is possible to improve the responsiveness and operation stability of cutting off the connection between the low-pressure chamber **4**-*b* and the valve chamber **3**-*b* by the control valve element **6**. In addition, when the actuator **2** is not driven, by biasing the control valve element **6** toward the low pressure chamber **4**-*b*, it is possible reliably maintain the connection between the low-pressure chamber **4**-*b* and the valve chamber **3**-*b* in a blocked state.

Due to the common orifice **25**, an amount of fuel flowing into the control chamber **11** is regulated, and an amount of fuel flowing out of the control chamber **11** is regulated. Accordingly, as compared to a fuel injection valve **100** which does not include the common orifice, the rate of increase and decrease of pressure in the control chamber **11** may be regulated. As such, it is possible to regulate the lift speed of the needle **17**.

Due to the outer orifice **24**, an amount of fuel flowing from the control chamber **11** through the middle chamber **23** and out into the valve chamber **3**-*b* is regulated. Accordingly, for example by regulating the fuel flow amount to be less as compared to a fuel supply rate supplied from the high pressure chamber **30**, it is possible to reduce the depressurization rate of the control chamber **11**, and thus more easily perform a fuel injection with a rectangular injection rate.

Along with the valve body **8**, the substantially cylindrical valve cylinder **9** is disposed so as to separate the control valve element **6** from the high pressure chamber **30**. Accordingly, a pressure is applied by the high pressure chamber **30** on the outer circumferential surface of the valve cylinder **9**. As a result, due to the pressure applied on the outer circumferential surface of the valve cylinder **9**, a gap between the valve cylinder **9** and the control valve element **6** is suppressed from increasing. As such, when the fuel pressure in the valve chamber **3**-*b* decreases, it is possible to suppress increases in a leak rate of fuel in the valve cylinder **9** leaking into the valve chamber **3**-*b*.

Due to the cylinder spring **20**, the valve cylinder **9** is biased toward the actuator **2**. Accordingly, when the actuator **2** is driven, it is easier to cut off the high pressure chamber **30** and the valve chamber **3**-*b*.

The oil-tight chamber **16** is formed by a space defined by the portion of the needle **17** around the lower end of the pressing portion **35**, the lower portion of the large-diameter piston **12**, and the portion of the nozzle body **15** which protrudes into the lower body **10**. Due to such a configuration, the driving force of the actuator **2** is transmitted through the fuel in the oil-tight chamber **16** to the large-diameter piston **12**, and it is possible to cause the needle **17** to lift.

The area Slarge in which the large-diameter piston **12** presses against the fuel in the oil-tight chamber **16** is set to be greater than the area Ssmall in which the fuel in the oil-tight chamber **16** presses against the pressing portion **35**. For this reason, the lift amount of the needle **17** may be greater than the extension amount of the actuator **2**.

The actuator **2** is formed of piezo elements. Accordingly, as compared to magnetostrictors or the like, responsiveness may be increased and the actuator **2** may be formed in a compact manner.

The ECU **33**-*a* includes two charge control modes for charging the actuator **2**. Of these, in the direct acting assist mode, the charge energy timing is set to be later than when the fuel pressure of the control chamber **11** reaches the return pressure (depressurization completion timing). The needle **17** moves in a direction that causes fuel to be injected from the injection hole **19** when both conditions of charge energy accumulated in the actuator **2** and pressure in the control chamber **11** are satisfied.

Accordingly, at the time of the charge energy timing, the needle **17** may be moved in a direction that causes fuel to be injected from the injection hole **19**. Further, in the hydraulic servo mode, the charge energy timing is set to be earlier than the depressurization completion timing. Accordingly, at the time of the depressurization completion timing, the needle **17** may be moved in a direction that causes fuel to be injected from the injection hole **19**.

The direct acting assist mode is set such that the final charge is greater than in the hydraulic servo mode. For this reason, in the direct acting assist mode, the force causing the needle **17** to be moved in a direction that causes fuel to be injected from the injection hole **19** is greater than in the hydraulic servo mode. Accordingly, in the direct acting assist mode, a fuel injection may be performed with a more rectangular injection rate than in the hydraulic servo mode.

In the direct acting assist mode, the valve opening energy timing is set to be earlier than the valve opening energy timing in the hydraulic servo mode. By reducing the amount of time until reaching the valve opening energy Evlv, the control chamber **11** may be depressurized earlier by this difference.

In addition, the above described embodiment may be modified and implemented as follows.

The actuator **2** is formed of piezo elements. Alternatively, the actuator **2** may be formed of, for example, magnetostrictors.

In the above described embodiment, due to the cylinder spring **20**, the valve cylinder **9** is biased toward the actuator **2**. Alternatively, the cylinder spring **20** may be not provided. In this case as well, when the actuator **2** is driven, the control chamber **11** may be depressurized.

In the above described embodiment, due to the valve spring **7**, the control valve element **6** is biased toward the low pressure chamber **4**-*b*. Alternatively, the valve spring **7** may be not provided. In this case as well, due to the high pressure fuel from the high pressure chamber **30** flowing through the middle chamber **23** and into the valve chamber **3**-*b*, a closing force may be applied on the control valve element **6**.

The section of the small-diameter piston portion **27** of the needle **17** which receives the pressure of the fuel in the control chamber **11** has a projection area Sctrl when projected in the movement direction of the needle **17**. Further, the portion of the needle **17** exposed to the injection hole **19** has a projection area Sseat when projected in the movement direction of the needle **17**. Here, Sctrl is set to be smaller than Sseat. Alternatively, the projection area Sctrl may be set to be equal to the projection area Sseat. In this case as well, if the large-diameter piston **12** is not pressed by the control valve element **6**, the needle **17** is not moved in a direction that causes fuel to be injected from the injection hole **19**. Alternatively, the projection area Sctrl may be set to be greater than the projection area Sseat. In this case, while there is a concern that the needle **17** may open due to the control chamber depressurizing, the amount of energy required to charge the actuator **2** to cause the needle **17** to lift may be further reduced.

The common orifice **25**, which regulates the inflow and outflow amounts of fuel, is disposed in the large-diameter piston **12**. Alternatively, the common orifice **25** may be not provided, and instead a passage with about the same cross sectional area as the middle-chamber **23** may be used. In this case as well, by controlling the magnitude of the charge energy ultimately charged to the actuator **2**, the lift speed of the needle **17** may be controlled.

The outer orifice **24**, which regulates the fuel flowing in the middle chamber **23**, is disposed in the control valve element **6**. Alternatively, without providing the outer orifice **24**, a passage with about the same cross sectional area as the middle chamber **23** may be used instead. In this case as well, by controlling the magnitude of the charge energy ultimately charged to the actuator **2**, the rising angle of the injection rate may be regulated downward.

The area Slarge in which the large-diameter piston **12** presses against the fuel in the oil-tight chamber **16** is set to be greater than the area Ssmall in which the fuel in the oil-tight chamber **16** presses against the pressing portion **35**. Alternatively, for example, the area Slarge in which the large-diameter piston **12** presses against the fuel in the oil-tight chamber **16** may be set to be equal to, or smaller than, the area Ssmall in which the fuel in the oil-tight chamber **16** presses against the pressing portion **35**. In this case, the amount of force that the pressing portion **35** is pressed by the fuel in the oil-tight chamber **16** (in other words, a force causing the needle **17** to move in a direction that opens the injection hole **19**) may be increased. In other words, the force that the actuator **2** needs to drive the large-diameter piston **12** with may be reduced.

The ECU **33**-*a* includes the direct acting assist mode and the hydraulic servo mode which have different charge energy timings. The charge energy timing is defined as when reaching a required amount of charge energy from the start of charging the actuator **2** until the needle **17** is moved in a direction that causes fuel to be injected from the injection hole **19**. Alternatively, the ECU **33**-*a* may include charge control modes other than these.

In both the direct acting assist mode and the hydraulic servo mode, the actuator **2** is charged for a fixed period. Alternatively, the actuator **2** may be charged for different periods of time in the direct acting assist mode and the hydraulic servo mode, as long as that the amount of charge energy ultimately charged to the actuator **2** is greater in the direct acting assist mode than in the hydraulic servo mode.

In the direct acting assist mode, the valve opening energy timing is set to be earlier than the valve opening energy timing in the hydraulic servo mode. Alternatively, the valve opening energy timing in the direct acting assist mode may be later than the valve opening energy timing in the hydraulic servo mode, as long as that the amount of charge energy ultimately charged to the actuator **2** is greater in the direct acting assist mode than in the hydraulic servo mode.

In the above described embodiment, the configuration which presses the needle **17** through the fuel in the oil-tight chamber **16** may be replaced by disposing a lever member in the high pressure chamber **30** directly below the large-diameter piston **12** and the pressing portion **35**. In this case, when the actuator **2** is driven, the control valve element **6** presses the large-diameter piston **12** toward the needle **17**. Due to this, the large-diameter piston **12** presses one end of the level member, and through lever action, the other end of the lever member lifts the pressing portion **35** up toward the actuator **2**. Accordingly, the needle **17** may be moved in a direction that causes fuel to be injected from the injection hole **19**.

In the above described embodiment, the valve spring **7**, the nozzle spring **14**, and the cylinder spring **20** are formed by springs (e.g., coil), but alternatively, may be formed by other elastic members (e.g., rubber).

When the needle **17** is moved in a direction that causes fuel to be injected from the injection hole **19**, this movement amount may be designed to be greater than a first predetermined amount which is set to be lower than a maximum movement amount, such that the end surface of the small-diameter piston portion **27** toward the actuator **2** abuts an inner surface of the large-diameter piston **12** that faces this end surface. Due to such a design, once the end surface of the small-diameter piston portion **27** toward the actuator **2** abuts the inner surface of the large-diameter piston **12** that faces this end surface, then the driving force of the actuator **2** is directly transmitted through the large-diameter piston **12** to the needle **17**. In other words, by controlling the extension and contraction of the actuator **2**, the movement of the needle **17** may be controlled.

According to the present modified example, the control valve element **6** moves toward the needle **17** or toward the actuator **2** in accordance with the extension and contraction of the actuator **2**. During this movement, there is a concern that there may be a period during which the low pressure chamber **4**-*b* and the high pressure chamber **30** are communicated through the valve chamber **3**-*b*, such that the fuel in the high pressure chamber **30** flows into the low pressure chamber **4**-*b* (hereinafter, referred to as a switching leak). This is especially a concern when performing multi-stage injections, in which the low pressure chamber **4**-*b* and the high pressure chamber **30** may be communicated through the valve chamber **3**-*b* over many periods, resulting in a large switching leak.

However, when performing a multi-stage injection, during the first stage injection, the needle **17** is moved toward the actuator **2** by depressurizing the fuel pressure in the control chamber **11**. Then, once the needle **17** exceeds the first predetermined amount, the end surface of the small-diameter piston portion **27** toward the actuator **2** abuts the inner surface of the large-diameter piston **12** that faces this end surface. Thereafter, each fuel injection aside from the final injection is performed while maintaining this abutment, such that the movement amount of the needle **17** is directly controlled through the large-diameter piston **12** by the extension and contraction driving of the actuator **2**. During the last stage injection, the fuel pressure in the control chamber **11** is increased, and the needle **17** is moved toward the injection hole **19**.

Accordingly, during each fuel injection except the first injection and the final injection, the end surface of the needle **17** toward the actuator **2** is maintained in a state of abutting the large-diameter piston **12** due to the actuator **2** pressing on the control valve element **6**. During this period, the low-pressure chamber **4***b*, the valve chamber **3**-*b*, and the control chamber **11** are connected, and the high pressure chamber **30** is cut off from the control chamber **11**. Accordingly, it is possible to greatly suppress switching leaks.

In the above described embodiment, the flange portion **2***a* is connected to the lower end portion of the actuator **2**, and the lower end portion of the flange portion **2***a* is able to contact the drive transmission pin **5**. Alternatively, as shown in FIG. **10**, a displacement amplification chamber **50** may be further formed between the flange portion **2***a* and the drive transmission pin **5**.

This configuration will be described in detail. A flange portion **55** (corresponding to a large-diameter pin) is connected to the lower end portion of the actuator **2**. The low pressure chamber **4**-*b* is formed between the flange portion **55** and the valve body **8** which houses the valve cylinder **9**. A displacement amplification mechanism **51** is disposed in the low pressure chamber **4**-*b*. The displacement amplification mechanism **51** includes a fixed member **52**, a support cylinder **53**, a pin spring **54**, and a second cylinder spring **57**.

The support cylinder **53** is disposed above the valve body **8**. The upper portion of the support cylinder **53** is able to slidably support the lower portion of the flange portion **55**, which is connected to the lower end portion of the actuator **2**. In addition, the lower portion of the support cylinder **53** is able to slidably support a portion including the upper end portion of a drive transmission pin **56**. The upper end portion of the support cylinder **53** is slidably supported by the fixed member **52**. The upper end surface of the fixed member **52** abuts a housing member **58** that houses the entirety of the actuator **2**. the second cylinder spring **57** is disposed on the outer periphery of the support cylinder **53**. The upper end of the second cylinder spring **57** abuts the fixed member **52**, and in this state, the second cylinder spring **57** biases the support cylinder **53** in a direction such that the lower end of the support cylinder **53** abuts the valve body **8**.

The drive transmission pin **56** acts as a valve element contact pin, and includes a mid-diameter portion **56**-*a*, a large-diameter portion **56**-*b*, and a small-diameter portion **56**-*c*.

The mid-diameter portion **56**-*a* includes the upper end portion of the drive transmission pin **56**, and the lower end portion of the mid-diameter portion **56**-*a* is coupled to the upper end portion of the large-diameter portion **56**-*b*. Further, the outer diameter of the mid-diameter portion **56**-*a* is smaller than the outer diameter of the flange portion **55** lower portion. The support cylinder **53** slidably supports a portion including the upper end portion of the mid-diameter portion **56**-*a*.

The upper end portion of the large-diameter portion **56**-*b* is coupled to the lower end portion of the mid-diameter portion **56**-*a*, and the lower end portion of the large-diameter portion **56**-*b* is coupled to the upper end portion of the small-diameter portion **56**-*c*. Further, the outer diameter of the large-diameter portion **56**-*b* is greater than the outer diameters of the mid-diameter portion **56**-*a* and the small-diameter portion **56**-*c*. Specifically, the outer diameter of the large-diameter portion **56**-*b* is equal to the outer diameter of the flange portion **55** lower portion. The large-diameter portion **56**-*b* is slidably supported by the support cylinder **53**.

The upper end portion of the small-diameter portion **56**-*c* is coupled to the lower end portion of the large-diameter portion **56**-*b*. Further, the outer diameter of the small-diameter portion **56**-*c* is smaller than the outer diameter of the mid-diameter portion **56**-*a*. The lower end portion of the small-diameter portion **56**-*c* is inserted into the valve body **8**, and is abuttable with the upper end portion of the control valve element **6**.

The support cylinder **53** slidably supports a portion including the upper end portion of the mid-diameter portion **56**-*a*. Accordingly, the middle portion of the support cylinder **53** has a smaller inner diameter than the upper and lower portions thereof. At this time, a space is formed by the upper end portion of the large-diameter portion **56**-*b*, the outer circumferential surface of the mid-diameter portion **56**-*a*, and the inner circumferential surface of the lower portion of the support cylinder **53**. The pin spring **54** is disposed in the formed spaced. Due to this pin spring **54**, the transmission drive pin **56** is biased toward the injection hole **19**.

The lower end portion of the flange portion **55** faces toward the upper end portion of the drive transmission pin **56**. In addition, the displacement amplification chamber **50** is formed as a space defined by the lower end portion of the flange portion **55**, the upper end portion of the drive transmission pin **56** (i.e., the upper end portion of the mid-diameter portion **56**-*a*), and the inner circumferential surface of the upper portion of the support cylinder **53**. At this time, due to the relationship between the outer diameter of the lower end portion of the flange portion **55** and the outer diameter of the mid-diameter portion **56**-*a*, an area in which the flange portion **55** presses against fuel in the displacement amplification chamber **50** is greater than an area in which the fuel in the displacement amplification chamber **50** presses against the drive transmission pin **56**.

According to the above described configuration, the area in which the flange portion **55** presses against the fuel in the displacement amplification chamber **50** is designed to be greater than the area in which the fuel in the displacement amplification chamber **50** presses against the drive transmission pin **56**. For this reason, according to Pascal's theorem, when the driving force of the actuator **2** is transmitted through the fuel in the displacement amplification chamber **50** to the drive transmission pin **56**, the displacement amount of the drive transmission pin **56** may be greater than the extension amount of the actuator **2**. The displacement amplification mechanism **51** and the flange portion **55** thus together act as an increase mechanism that increases a displacement amount by which the control valve element **6** is displaced due to the actuator **2** extending.

In the above described embodiment, the pressing chamber **34** is formed in the large-diameter piston **12**, and the pressing chamber **34** houses a portion of the needle **17**. Alternatively, as shown in FIG. **11**, in addition to housing a portion of the needle **17**, the pressing chamber **34** may house a second cylinder **60**.

The configuration of the needle **17** is based on the above described embodiment. Specifically, the small-diameter piston portion **27** is inserted into the nozzle spring **14** which is housed within the pressing chamber **34**. The lower end portion of the small-diameter piston portion **27** is coupled to the upper end portion of the pressing portion **35**, and the lower end portion of the pressing portion **35** is coupled to the circular column portion **45**.

In the present modified example, the lower end portion of the pressing portion **35** abuts the upper end portion of an abutment member **64**. The abutment member **64** is disposed so as to surround the circular column portion **45**. The lower end portion of the abutment member **64** is inserted into the nozzle body **15**.

The second cylinder **60** is housed in the pressing chamber **34** so as to surround the needle **17**. An annular protrusion portion **60***a* that protrudes toward the circular column portion **45** is formed at the inner circumferential surface of the lower portion of the second cylinder **60**.

Meanwhile, an annular protrusion portion **64***a* that protrudes toward the second cylinder **60** is formed at the inner circumferential surface of the lower portion of the abutment member **64**. Accordingly, when the needle **17** is preventing fuel injection from the injection hole **19** (i.e., when the seat surface **331** of the needle **17** is seated on the seating surface **221**), the protrusion portion **64***a* of the abutment member **64** faces the protrusion portion **60***a* of the second cylinder **60** in the axial direction of the needle **17**. A gap is formed between the inner circumferential surface of the protrusion portion **60***a* of the second cylinder **60** and the outer circumferential surface of the abutment member **64**.

An oil-tight chamber **61** is defined by the lower body **10**, the lower portion of the large-diameter piston **12**, the lower portion of the second cylinder **60**, the abutment member **64**, and the upper end of the nozzle body **15**. Further, when the actuator **2** is in a contracted state, the second cylinder **60** is pressed by the abutment member **64** toward the injection hole **19**, and a first gap **62** is formed between an end portion of the second cylinder **60** toward the actuator **2** and a surface of the large-diameter piston **12** that faces this end portion.

The first communication passage **26** is disposed in the large-diameter piston **12** such that high pressure fuel flows in from the high pressure chamber **30**. A third communication passage **63** is disposed in the second cylinder **60** such that fuel is able to flow in through the first communication passage **26**. When configured in this manner, by connecting the first communication passage **26** with the third communication passage **63**, fuel from the high pressure chamber **30** flows into the pressing chamber **34**.

According to the present modified example, when the actuator **2** is in a contracted state, the first gap **62** exists between an end portion of the second cylinder **60** toward the actuator **2** and the surface of the large-diameter piston **12** that faces this end portion. Accordingly, as shown on the left in FIG. **12**, when the actuator **2** extends, the driving force of the actuator **2** is transmitted by the large-diameter piston **12** through the fuel in the oil-tight chamber **61** to the second cylinder **60**. As a result, the second cylinder **60** is moved, together with the needle **17**, toward the actuator **2** until the first gap **62** is closed. At this time, the protrusion portion **64***a* of the abutment member **64** is abutting the protrusion portion **60***a* of the second cylinder **60**.

However, when the first gap **62** is closed, as shown in the middle of FIG. **12**, the second cylinder **60** is pressed toward the actuator **2** by the large-diameter piston **12**. Accordingly, the protrusion portion **60***a* of the second cylinder **60** separates from the protrusion portion **64***a* of the abutment member **64**. Then, together with the large-diameter piston **12**, the protrusion portion **60***a* of the second cylinder **60** presses against the fuel in the oil-tight chamber **61**, and the driving force of the actuator **2** is transmitted through the fuel in the oil-tight chamber **61** to the needle **17**.

When the actuator **2** contracts, as shown on the right of FIG. **12**, the pressing force from the actuator **2** on the control valve element **6** is gone, and so due to the valve spring **7**, the control valve element **6** is biased toward the actuator **2**. Accordingly, the pressing force from the control valve element **6** on the large-diameter piston **12** is also gone, and so due to the nozzle spring **14** housed in the pressing chamber **34**, the large-diameter piston **12** is biased through the needle cylinder **13** toward the actuator **2**. Further, since the control valve element **6** separates from the large-diameter piston **12**, the high pressure chamber **30** becomes connected with the control chamber **11**, and fuel from the high pressure chamber **30** flows into the control chamber **11**, thereby increasing the pressure in the control chamber **11**.

Due to this, the needle **17** moves toward the injection hole **19**, and the pressing portion **35** presses the abutment member **64** toward the injection hole **19**. As a result, the protrusion portion **64***a* of the abutment member **64** abuts the protrusion portion **60***a* of the second cylinder **60**. Then, since the abutment member **64** presses the second cylinder **60** toward the injection hole **19**, the second cylinder **60** also moves toward the injection hole **19**. Due to this, the first gap **62** is formed between an end portion of the second cylinder **60** toward the actuator **2** and the surface of the large-diameter piston **12** that faces this end portion.

When configured in this manner, it is possible to change from a state in which the large-diameter piston **12** alone causes the needle **17** to move in a direction that causes fuel to be injected from the injection hole **19**, to a state in which the driving force of the actuator **2** is increased and transmitted to the needle **17**.

Regarding the present modified example, a displacement amplification ratio α of when only the large-diameter piston **12** is pressing on the fuel in the oil-tight chamber **61** is configured to be smaller than a displacement amplification ratio α' of when both the second cylinder **60** and the large-diameter piston **12** are pressing on the fuel in the oil-tight chamber **61**. In this case, additional effects may be exhibited. Specifically, as shown in FIG. **13**, the portion of the large-diameter piston **12** that presses on the fuel in the oil-tight chamber **61** has an area of **S1**. Further, the portions of the second cylinder **60** and the needle **17** pressed by the fuel in the oil-tight chamber **61** has a total area of **S2**.

Here, the displacement amplification ratio α corresponds to a quotient of dividing the area **S1** by the area **S2**. In addition, the portions of the large-diameter piston **12** and the cylinder that press on the fuel in the oil-tight chamber **61** has a total area of S1'. Further, the portion of the needle **17** pressed by the fuel in the oil-tight chamber **61** has an area of S2'. Here, the displacement amplification ratio α' corresponds to a quotient of dividing the area S1' by the area S2. The displacement amplification ratio α calculated as described above is configured to be smaller than the displacement amplification ratio α'.

According to the above described configuration, it is possible to reduce the movement amount of the needle **17** toward the actuator **2** when only the large-diameter piston **12** is pressing on the fuel in the oil-tight chamber **61**. Conversely, it is possible to increase the movement amount of the needle **17** toward the actuator **2** when both the second cylinder **60** and the large-diameter piston **12** are pressing on the fuel in the oil-tight chamber **61**. In addition, it is possible to increase the driving force to the needle **17** when only the large-diameter piston **12** is pressing on the fuel in the oil-tight chamber **61**.

Conversely, it is possible to decrease the driving force to the needle **17** when both the second cylinder **60** and the large-diameter piston **12** are pressing on the fuel in the oil-tight chamber **61**.

According to the above described embodiment, as shown in FIG. **2**, the oil-tight chamber **16** is defined by the portion of the needle **17** around the lower end of the pressing portion **35**, the lower portion of the large-diameter piston **12**, and the portion of the nozzle body **15** which protrudes into the lower body **10**. In this case, when the needle **17** moves toward the actuator **2** due to the fuel pressure in the control chamber **11** decreasing or the like, the volume in the oil-tight chamber **16** increases and the fuel pressure in the oil-tight chamber **16** decreases (refer to the left of FIG. **14**).

As the fuel pressure in the oil-tight chamber **16** decreases, the large-diameter piston **12** may move in a direction that suppresses the fuel pressure in the oil-tight chamber **16** from decreasing, and therefore there is a concern that the control valve element **6** may fail to block the connection between the high pressure chamber **30** and the control chamber **11**. In this case, the fuel pressure in the control chamber **11** would increase, and suppress the needle **17** from moving in a direction that causes fuel to be injected from the injection hole **19**.

As a countermeasure to this, as shown on the right of FIG. **14**, a third cylinder **70** that moves in the axial direction may be provided. The lower portion of the third cylinder **70** is supported by the inner circumferential surface of the nozzle body **15** in an airtight manner, and the upper portion of the third cylinder **70** is supported by the inner circumferential surface of the large-diameter piston **12** in an airtight manner. Specifically, the portion of the nozzle body **15** that protrudes into the lower body **10** (hereinafter referred to as a protrusion portion) includes two stepped portions at a side surface that faces the needle **17**. The stepped portions are indented in a stepped shape in a direction orthogonal to the axial direction. Of these, the stepped portion toward the needle **17** and the injection hole **19** is referred to as a first stepped portion **73**, while the stepped portion toward the protrusion portion upper end of the nozzle body **15** is referred to as a second stepped portion **74**.

The lower end portion of the third cylinder **70** is abuttable with the first stepped portion. An oil-tight chamber **72** is formed by the large-diameter piston **12**, the third cylinder **70**, and the nozzle body **15**. a third cylinder spring **71** is housed in the oil-tight chamber **72**. The upper end portion of the third cylinder spring **71** abuts the upper portion of the third cylinder **70**, and the lower end portion of the third cylinder spring **71** abuts the second stepped portion **74**. The third cylinder spring **71** biases the third cylinder **70** toward the actuator **2**.

The operation of the fuel injection valve of the present modified example will be explained. When the actuator **2** is in a contracted state, the fuel pressure in the control chamber **11** is high, and thus the needle **17** moves toward the injection hole **19** and blocks fuel from flowing toward the injection hole **19**. In this case, the needle **17** is pressing against the third cylinder **70**, and since the pressing force of the third cylinder **70** on the oil-tight chamber **72** is transmitted to the large-diameter piston **12**, the large diameter piston **12** moves toward the actuator **2**.

When the actuator **2** extends, the large-diameter piston **12** is pressed by the control valve element **6**. The pressing force of the large-diameter piston **12** on the oil-tight chamber **72** is transmitted through the third cylinder **70** to the needle **17** which abuts the upper end surface of the third cylinder **70**. As a result, the needle **17** moves toward the actuator **2**.

According to such a configuration, even if the needle **17** moves in a direction that causes fuel to be injected from the injection hole **19** due to, for example, the control chamber **11** depressurizing, the oil-tight chamber **72** is isolated from the needle **17**, and therefore the fuel pressure in the oil-tight chamber **72** is not affected. Accordingly, the fuel pressure in the oil-tight chamber **72** only changes based on the movement of the large-diameter piston **12**, and the movement of the needle **17** may be stabilized.

In the above described embodiment, as shown in FIG. **2**, the control valve element **6** is slidably supported by the second valve body **8**-*b* and the valve cylinder **9**. Alternatively, the valve cylinder **9** may be not provided, and as shown in FIG. **15** for example, the control valve element **6** may be split into two parts.

Specifically, the control valve element **6** includes a second chamber connection member **80** and a first chamber connection member **81**. The second chamber connection member **80** is slidably supported by the second valve body **8**-*b*. The upper end portion of the second chamber connection member **80** is connected to the lower end portion of the drive transmission pin **5**, and the lower end portion of the second chamber connection member **80** is formed to be abuttable with the upper end portion of the first chamber connection member **81**.

In addition, a large-diameter piston **86** is configured such that the upper portion of the large-diameter piston **86** surrounds the first chamber connection member **81**. Further, a first piston spring **82** is disposed surrounding the large-diameter piston **86**. The first piston spring **82** biases to separate the second valve body **8**-*b* from a fixed member **88**.

The upper end portion of the first piston spring **82** is attached to the second valve body **8**-*b*, and the lower end portion of the first piston spring **82** is attached to a stepped portion **88**-*a* of the fixed member **88**. The lower end portion of the fixed member **88** abuts a second lower body **10**-*a* which is described later. Further, the stepped portion **88**-*a*, which is intended in a stepped manner, is formed on the outer circumferential surface of the fixed member **88**.

The second lower body **10**-*a* is housed within the lower body **10**. In addition, the second lower body **10**-*a* abuts the upper end portion of the nozzle body **15**, and slidably supports the upper portion of the circular column portion **45**. The outer circumferential surface of the second lower body **10**-*a* is separated from the inner circumferential surface of the lower body **10**. Further, the lower portion of the second lower body **10**-*a* has a high pressure fuel communication passage **10**-*b* formed therein. Accordingly, the fuel in the high pressure chamber **30** flows through the high pressure fuel communication passage **10**-*b* toward the first high pressure passage **41**.

The outer diameter of the lower portion of the large-diameter piston **86** is formed to be smaller than the outer diameter of the upper portion of the same. Further, the lower portion of the large-diameter piston **86** is slidably supported by the fixed member **88**.

A second piston spring **87** is disposed in a space formed between the first piston spring **82**, the lower portion of the large-diameter piston **86**, and the upper end portion of the fixed member **88**. The second piston spring **87** biases the large-diameter piston **86** toward the actuator **2**, and causes the first chamber connection member **81** to abut with an annular protrusion portion **86***a* formed on the inner circumferential surface of the large-diameter piston **86**. Accordingly, when the actuator **2** is in a contracted state, a second gap **89** exists between the upper end portion of the needle cylinder **13** and the lower end portion of the protrusion portion **86***a* of the large-diameter piston **86**.

The pressing chamber **34** is formed in the large-diameter piston **86**. The configuration in the pressing chamber **34** is the same as the configuration of the above described embodiment. Further, in the same manner as the configuration of the above described embodiment, the first communication passage **26** is disposed in the large-diameter piston **86** such that the high pressure fuel from the high pressure chamber **30** flows in.

The oil-tight chamber **16** is formed by the lower end portion of the large-diameter piston **86**, the portion of the needle **17** around the lower end of the pressing portion **35**, the fixed member **88**, and the upper end portion of the second lower body **10**-*a*.

The bottom end portion of the first chamber connection member **81** is configured such that a portion thereof is separated from the upper surface of the needle cylinder **13**, while another portion thereof abuts the needle cylinder **13**. In the present modified example, a conical cavity portion **84** is formed so as to have an apex at substantially the center of the first chamber connection member **81**, with the lower end portion of the first chamber connection member **81** which abuts the needle cylinder **13** as a base. For this reason, when the lower end portion of the first chamber connection member **81** abuts the needle cylinder **13**, the control chamber **11** includes the cavity portion **84**, and the capacity of the control chamber **11** is increased.

A first middle chamber **85**, which is a flow path in which fuel flows, is disposed inside the first chamber connection member **81**. The lower portion of the first middle chamber **85** opens at the apex of the cavity portion **84** through a third common orifice **85**-*a*. Further, the upper portion of the first middle chamber **85** opens at the upper end portion of the first chamber connection member **81**. When the lower end portion of the second chamber connection member **80** is separated from the upper end portion of the first chamber connection member **81**, the high pressure chamber **30** and the cavity portion **84** are connected to each other through the first middle chamber **85** and the third common orifice **85**-*a*.

A second middle chamber **83**, which is a flow path in which fuel flows, is disposed inside the second chamber connection member **80**. The lower portion of the second middle chamber **83** opens at the lower end portion of the second chamber connection member **80**. The upper portion of the second chamber connection member **80** is connected to the valve chamber **3**-*b* through the outer orifice **24**. Accordingly, when the lower end portion of the second chamber connection member **80** is separated from the upper end portion of the first chamber connection member **81**, the high pressure chamber **30** and the valve chamber **3**-*b* are connected to each other through the second middle chamber **83** and the outer orifice **24**.

When the lower end portion of the second chamber connection member **80** abuts the upper end portion of the first chamber connection member **81**, both the connection between the high pressure chamber **30** and the cavity portion **84** through the first middle chamber **85** and the third common orifice **85**-*a*, as well as the connection between the high pressure chamber **30** and the valve chamber **3**-*b* through the second middle chamber **83**, are blocked. Conversely, the cavity portion **84** and the valve chamber **3**-*b* are connected to each other through the outer orifice **24**, the second middle chamber **83**, the first middle chamber **85**, and the third common orifice **85**-*a*.

According to the configuration of the present modified example, when the control chamber **11** depressurizes and the needle **17** moves in a direction that causes fuel to be injected from the injection hole **19**, the pressure of the fuel in the oil-tight chamber **16** decreases. As the pressure of the fuel in the oil-tight chamber **16** decreases, there is a concern that the first chamber connection member **81** will move toward the injection hole **19**, thereby causing the second chamber connection member **80** to separate from the first chamber connection member **81**, and connecting the control chamber **11** with the high pressure chamber **30**.

If the control chamber **11** is connected with the high pressure chamber **30**, the pressure of the fuel in the control chamber **11** will rise, thereby suppressing the needle **17** from moving in a direction that causes fuel to be injected from the injection hole **19**. Here, the second piston spring **87** causes the large-diameter piston **86** and the first chamber connection member **81** to abut each other. For this reason, if the pressure of the fuel in the oil-tight chamber **16** decreases, the large-diameter piston **86** moves toward the injection hole **19**, and thus is able to suppress the pressure of the fuel in the oil-tight chamber **16** from decreasing.

However, if the large-diameter piston **86** moves in a direction that suppresses the fuel pressure in the oil-tight chamber **16** from decreasing, there is a concern that the large-diameter piston **86** may press on the needle cylinder **13** at that time. As a countermeasure to this, the second gap **89** exists between the upper end portion of the needle cylinder **13** and the lower end portion of the protrusion portion **86***a* of the large-diameter piston **86**.

Due to being configured in this manner, even if, for example, the large-diameter piston **86** moves in a direction that suppresses the fuel pressure in the oil-tight chamber **16** from decreasing, the needle cylinder **13** will not be pressed against by the large-diameter piston **86** until the second gap **89** is closed. Further, since the first chamber connection member **81** is independent of the large-diameter piston **86**, the first chamber connection member **81** does not move according to the movement of the large-diameter piston **86**. Accordingly, the large-diameter piston **86** is able to suppress the oil-tight chamber **16** from depressurizing, without affecting the first chamber connection member **81** or the needle cylinder **13**.

Regarding the present modified example, the second gap **89** may be set so as to be greater than a maximum movement amount of the large-diameter piston **86**, which is calculated by dividing a maximum movement amount of the needle **17** in a direction that causes fuel to be injected from the injection hole **19** by the displacement amplification ratio.

Specifically, the area of the portion of the large-diameter piston **86** that presses on the fuel in the oil-tight chamber **16** is divided by the area of the portion of the needle **17** pressed by the fuel in the oil-tight chamber **16** in a direction that causes fuel to be injected from the injection hole **19**. The quotient from this calculation corresponds to the displacement amplification ratio of how much the needle **17** is moved in a direction that causes fuel to be injected from the injection hole **19** with respect to the movement amount of the large-diameter piston **86**. Accordingly, the movement amount of the needle **17** in a direction that causes fuel to be injected from the injection hole **19** may be calculated from the product of the movement amount of the large-diameter piston **86** and the displacement amplification ratio. Due to this, it is understood that the movement amount of the large-diameter piston **86** may be calculated by dividing the movement amount of the needle **17** in a direction that causes fuel to be injected from the injection hole **19** by the displacement amplification ratio.

Meanwhile, when the movement amount of the needle **17** in a direction that causes fuel to be injected from the injection hole **19** is at its maximum value, the movement amount of the large-diameter piston **86** toward the injection hole **19** is at its maximum value. Based on the above, the width of the second gap **89** may be set to be greater than the maximum movement amount of the large-diameter piston **86**, which is calculated by dividing the maximum movement amount of the needle **17** in a direction that causes fuel to be injected from the injection hole **19** by the displacement amplification ratio. Due to this, it is possible to reduce the likelihood of the large-diameter piston **86** contacting the needle cylinder **13** even when the large-diameter piston **86** has moved the maximum amount toward the needle cylinder **13**.

According to the above described embodiment, as shown in FIG. **16**, from the upper end portion of the control chamber **11** to the upper end portion of the small-diameter piston portion **27**, the area is formed to be constant. In this case, when the actuator **2** extends, the high pressure chamber **30** is blocked from the control chamber **11**, and the control valve element **6** connects the low pressure chamber **4**-*b*, the valve chamber **3**-*b*, and the control chamber **11** with each other, so that the fuel in the control chamber **11** flows through the valve chamber **3**-*b* and into the low pressure chamber **4**-*b*. However, when the actuator **2** extends, the fuel from the control chamber **11** may also flow out from a path other than the path through the middle chamber **23** and the outer orifice **24**. A plurality of examples of this are provided below.

(1) As shown in FIG. **17**, the upper end portion of a needle cylinder **90** may be configured to be exposed in a control chamber **91**. At this time, a portion that does not abut a large-diameter piston **112** is formed on the upper end surface of the needle cylinder **90** in the control chamber **91**. Due to being configured in this manner, a diameter ds (area) of the upper end surface of the control chamber **91** is set to be greater than a diameter dc (area) of the lower end surface of the control chamber **91**. Accordingly, when the fuel pressure in the control chamber **91** increases, the fuel pressure in the control chamber **91** generates a force that causes the needle cylinder **90** to move toward the injection hole **19**.

According to such a configuration, when the actuator **2** extends so that the control valve element **6** connects the low pressure chamber **4**-*b*, the valve chamber **3**-*b*, and the control chamber **91** to each other while blocking the high pressure chamber **30** from the control chamber **91**, the control chamber **91** is compressed by the needle **17** or the control valve element **6**, and the fuel pressure in the control chamber **91** increases. As shown by the top of FIG. **18**, this increased fuel pressure exceeds the pressure of the fuel in the high pressure chamber **30** for a period, and as shown in FIG. **19**, the upper end portion of the needle cylinder **90**, which is exposed in the control chamber **91**, is pressed toward the injection hole **19**. Due to this, the needle cylinder **90** moves toward the injection hole **19**, and the fuel in the control chamber **91** may leak out from there. Accordingly, the pressure of the fuel in the control chamber **91** may decrease faster. Therefore, as shown by the bottom of FIG. **18**, the movement speed of the needle **17** toward the actuator **2** may be faster as compared to the above described embodiment.

(2) As shown in the configuration of FIG. **20** as well, the upper end portion of a needle cylinder **110** is exposed in a control chamber **111**. However, the upper end surface of the needle cylinder **110** is formed such that an outer edge thereof abuts a large-diameter piston **112**, but an inner edge thereof does not abut the large-diameter piston **112**. In other words, the upper end surface of the needle cylinder **110** is sloped from a radially outward side to a radially inward side. In addition, a second outer orifice **113** that connects to the high pressure chamber **30** is formed in the large-diameter piston **112**. The second outer orifice **113** is blocked from the control chamber **111** when the upper end portion of the needle cylinder **110** abuts the large diameter piston **112**. Conversely, the control chamber **111** is connected to the high pressure chamber **30** through the second outer orifice **113** when the upper end portion of the needle cylinder **110** separates from the large diameter piston **112**.

When the fuel pressure in the control chamber **111** exceeds the fuel pressure of the high pressure chamber **30**, the end surface of the needle cylinder **110** which is exposed in the control chamber **111** and which faces the actuator **2** is pressed toward the injection hole **19**. Accordingly, the needle cylinder **110** moves toward the injection hole **19**, and the upper end surface of the needle cylinder **110** separates from the large-diameter piston **112**. At this time, the control chamber **111** and the high pressure chamber **30** are connected through the second outer orifice **113**. In this case, as shown in FIG. **21**, fuel in the control chamber **111** is able to flow out through the middle chamber **23** and the outer orifice **24** formed in the control valve element **6**, and is also able to flow out through the second outer orifice **113**.

Then, when the fuel in the control chamber **111** is depressurized, the needle cylinder **110** moves back toward the actuator **2**. Due to this, the upper end surface of the needle cylinder **110** abuts the large-diameter piston **112**, and the control chamber **111** is blocked from the second outer orifice **113** by the needle cylinder **110**. Accordingly, the possibility of fuel from the high pressure chamber **30** flowing through the second outer orifice **113** into the control chamber **111** is low, and the fuel pressure in the control chamber **111** may decrease in a smooth manner.

(3) As shown in FIG. **22**, in addition to the common orifice **25**, a second common orifice **121** that connects the control chamber **11** with the high pressure chamber **30** is formed in a large-diameter piston **120**. When configured in this manner, for example, when the movement speed of the needle **17** in a direction that causes fuel to be injected from the injection hole **19** is set to be slow (low speed valve opening control), the extension amount of the actuator **2** is controlled to be low. Accordingly, the control chamber **11** is not compressed by the needle **17** or the control valve element **6** to the extent that the fuel pressure in the control chamber **11** exceeds the fuel pressure of the high pressure chamber **30**. For this reason, as shown in FIG. **23**, as the fuel in the control chamber **11** depressurizes, fuel from the high pressure chamber **30** flows through the second common

orifice **121** and into the control chamber **11**. Accordingly, the depressurization speed of the control chamber **11** may be adjusted to be slower.

Conversely, when the movement speed of the needle **17** in a direction that causes fuel to be injected from the injection hole **19** is set to be fast (high speed valve opening control), the extension amount of the actuator **2** is controlled to be large. Accordingly, the control chamber **11** is compressed by at least one of the needle **17** and the control valve element **6**. Due to this, the fuel pressure in the control chamber **11** increases, and as shown in FIG. **23**B, fuel flows from the control chamber **11** through the second common orifice **121** to the high pressure chamber **30**. For this reason, the fuel in the control chamber **11** may be depressurized quickly.

The left side of FIG. **24** shows results comparing, according the configuration of the present modified example, the movement amount of the needle **17** toward the actuator **2** (needle lift amount) when performing a low speed valve opening control and when performing a high speed valve opening control. The right side of FIG. **24** compares injection rates for the same. According to the results on the left of FIG. **24**, it is understood that the maximum lift amount is reached earlier when performing a high speed valve opening control as compared to performing a low speed valve opening control. Further, since the maximum lift amount is reached earlier when performing a high speed valve opening control, in the right side of FIG. **24** as well, the injection rate during the early stage is also greater than when performing a low speed valve opening control.

In example (3), the second common orifice **121** is formed in the large-diameter piston **120**. However, it is not necessary to form the second common orifice **121** in the large-diameter piston **120**. For example, as shown in FIG. **25**A, the second common orifice **121** may be formed in the needle cylinder **122** to connect the control chamber **11** with the high pressure chamber **30**. Further, as shown in FIG. **25**B, the second common orifice **121** may be formed in the control valve element **123** to connect the middle chamber **23** with the high pressure chamber **30**. Alternatively, as shown in FIG. **25**C, a second middle chamber **127**, which is a flow path in which fuel flows, may be disposed in a small-diameter piston portion **126** included in a needle **124**. The upper portion of the second middle chamber **127** opens at the upper end portion of the small-diameter piston portion **126**, and is in communication with the control chamber **11**. Further, the second common orifice **121** is formed in the small-diameter piston portion **126** to connect the second middle chamber **127** with the high pressure chamber **30**. According to this configuration as well, the control chamber **11** and the high pressure chamber **30** are connected to each other by the small-diameter piston portion **126** through the second middle chamber **127** and the second common orifice **121**.

First Modified Embodiment

In the above described embodiment, as shown in FIG. **2**, the upper end portion of the control valve element **6** controls the connection relationship between the low pressure chamber **4**-*b* and the valve chamber **3**-*b*, while the lower end portion of the control valve element **6** controls the connection relationship between the valve chamber **3**-*b*, the control chamber **11**, and the high pressure chamber **30**. According to such a configuration, if the control valve element **6** is tilted or axially displaced, there is a concern that, for example, the low pressure chamber **4**-*b* may not be properly blocked from the valve chamber **3**-*b* when the actuator **2** is contracted, or the high pressure chamber **30** may not be properly blocked from the control chamber **11** when the actuator **2** is extended. As a countermeasure to this, as shown in FIG. **26**, a control valve element **130** may include a seating portion **131** and a sliding portion **132**. In this case, the lower end surface of the seating portion **131** is configured to abut with the upper end surface of the sliding portion **132**.

The upper end portion of the seating portion **131** abuts with the lower end portion of the drive transmission pin **5**. When the actuator **2** is in a contracted state, the upper end portion of the seating portion **131** seats on the seat portion **36** of the valve chamber **3**-*b*.

A third middle chamber **133**, which is a flow path in which fuel flows, is disposed in the sliding portion **132**. The lower portion of the third middle chamber **133** opens at the lower end portion of the sliding portion **132**, and is in communication with the inside of the valve cylinder **9**. Further, a third outer orifice **134** is formed in the sliding portion **132**. The third outer orifice **134** connects the upper portion of the third middle chamber **133** with the valve chamber **3**-*b*. In other words, the sliding portion **132** is able to connect the inside of the valve cylinder **9** with the valve chamber **3**-*b* through the third middle chamber **133** and the third outer orifice **134**.

According to the configuration of the first modified embodiment, while the lower end surface of the seating portion **131** and the upper end surface of the sliding portion **132** are connected and moving in the axial direction, even if one of these elements is axially displaced, the other element is not coupled to this axial displacement, and the effects thereof may be suppressed.

Regarding the first modified embodiment, as shown in FIG. **27**, the surface of the seating portion **131**, which contacts the seat portion **36** of the valve chamber **3**-*b* when the actuator **2** is in a contracted state, may be formed as a spherical surface. In this case, even if for example the seating portion **131** tilts, since the surface which contacts the seat portion **36** of the valve chamber **3**-*b* is a spherical surface, that tilt may be absorbed. Accordingly, while the actuator **2** is in a contracted state, it is possible to reliably block the low pressure chamber **4**-*b* from the valve chamber **3**-*b*, and reliably connect the high pressure chamber **30**, the valve chamber **3**-*b*, and the control chamber **11** to each other.

According to the first modified embodiment, the lower end surface of the seating portion **131** is configured to abut with the upper end surface of the sliding portion **132**. Alternatively, the lower end portion of the seating portion **131** and the upper end portion of the sliding portion **132** may be fitted to each other in a convex-concave fashion with a gap. Examples of this are provided below.

(4) As shown in FIG. **28**, a recessed portion, which recesses in a stepped manner toward the actuator **2**, is disposed in the middle of the lower end portion of the seating portion **131**. In addition, a protruding portion, which protrudes toward the seating portion **131**, is disposed in the middle of the upper end portion of the sliding portion **132**. At this time, the width of the recessed portion formed in the seating portion **131** is formed to be wider than the width of the protruding portion formed in the sliding portion **132**. In addition, the lower end portion of the seating portion **131** and the upper end portion of the sliding portion **132** are fitted to each other in a convex-concave fashion with a gap. When configured in this manner, as shown in FIG. **29**, it is assumed that the axis of the sliding portion **132** is axially offset with respect to a reference axis along which the actuator **2** extends and along which the needle **17** moves in a direction that opens the injection hole **19**. In this case, the axial displacement of the sliding portion **132** may be suppressed

from affecting the seating portion **131** over a range in which the protruding portion formed in the sliding portion **132** does not contact the recessed portion formed in the seating portion **131**.

The configuration of a modified example based on the configuration of (4) is shown in FIG. **30**. In (4), the control valve element **130** includes the seating portion **131** and the sliding portion **132**, a recessed portion which recesses in a stepped manner toward the actuator **2** is disposed in the middle of the lower end portion of the seating portion **131**, and a protruding portion which protrudes toward the seating portion **131** is disposed in the middle of the upper end portion of the sliding portion **132**. In FIG. **30**, a control valve element **140** includes a seating portion **141**, a sliding portion **142**, and a second seating portion **143**. According to this configuration, a protruding portion which protrudes toward the injection hole **19** is disposed in the middle of the lower end portion of the sliding portion **142**, while a recessed portion which recesses in a stepped manner toward the injection hole **19** is disposed in the middle of the upper end portion of the second seating portion **143**.

Here, the width, in a direction orthogonal to the axial direction, of the recessed portion disposed in the middle of the upper end portion of the second seating portion **143** is formed to be wider than the width, in the same direction, of the protruding portion formed in the middle of the lower end portion of the sliding portion **142**. In this state, the lower end portion of the sliding portion **142** and the upper end portion of the second seating portion **143** are fitting to each other in a convex-concave manner with a gap. Meanwhile, the upper end portion of the sliding portion **142** and the lower end portion of the seating portion **141** are configured in the same manner as the configuration described in (4). Accordingly, as the actuator **2** extends and contracts, the lower end portion of the sliding portion **142** and the upper end portion of the second seating portion **143**, as well as the upper end portion of the sliding portion **142** and the lower end portion of the seating portion **141**, move in the axial direction while fitted in a convex-concave manner.

When the actuator **2** extends, the second seating portion **143** abuts the large-diameter piston **12**. The surface of the second seating portion **143** that abuts the large-diameter piston **12** is formed as a spherical surface. Then, a seat member **144** is disposed at a predetermined location of the upper end portion of the large-diameter piston **12**, the predetermined location being the location assumed to abut with the lower end portion of the second seating portion **143**. The seat member **144** corresponds to the shape of the lower end portion of the second seating portion **143**. Accordingly, the lower end portion of the second seating portion **143** is in close contact with the top end portion of the large-diameter piston **12**. Here, in order to avoid hindering the fuel flow in the common orifice **25** of the large-diameter piston **12**, a portion of the seat member **144** is hollowed out such that the opening of the common orifice **25** toward the control valve element **140** is not blocked.

According to the configuration shown in FIG. **30**, in addition to the effects described under (4), when the actuator **2** is extended, it is possible to reliably maintain the connection between the low pressure chamber **4**-*b*, the valve chamber **3**-*b*, and the control chamber **11**, and also to reliably maintain the connection between the high pressure chamber **30** and the control chamber **11** in a blocked state.

(5) As shown in FIG. **31**, a protruding portion that protrudes toward the sliding portion **132** may be disposed in the center of the lower end portion of the seating portion **131**, and a recessed portion that recesses toward the injection hole **19** may be disposed in the center of the upper end portion of the sliding portion **132**. According to this configuration, in a similar manner as example (4), the lower end portion of the seating portion **131** and the upper end portion of the sliding portion **132** may be fitted to each other in a convex-concave fashion with a gap. Accordingly, the same effects as those described for example (4) may be exhibited.

As shown in FIG. **32**, the are of the upper end portion of a sliding portion **151** may be formed to be wider than the area of the lower end portion of a seating portion **150**, and an annular protruding portion **151***a* that protrudes toward the seating portion **150** may be disposed along the outer edge portion of the upper end portion of the sliding portion **151**. A gap is provided between the inner circumferential surface of the protruding portion **151***a* and the outer circumferential surface of the seating portion **150**. Accordingly, even if the sliding portion **151** is axially displaced, the axial displacement of the sliding portion **151** may be suppressed from affecting the seating portion **150** over a range in which the inner circumferential surface of the protruding portion **151***a* disposed on the upper end portion of the sliding portion **151** does not contact the outer circumferential surface of the seating portion **150**.

According to the first modified embodiment, the control valve element **130** includes the seating portion **131** and the sliding portion **132**. Alternatively, as shown in FIG. **33**, the sliding portion **132**, the large-diameter piston **12**, and the needle cylinder **13** may be integrally formed. This integrally formed member is referred to as an integral member **162**, and the specific configuration thereof is explained below.

The upper end surface of the nozzle body **160** and the lower end surface of the lower body **161** are locked in a state of abutting one another by a retainer nut or the like. A high pressure chamber **169** is formed in the lower body **161**. The high pressure chamber **169** houses a portion of the integral member **162**, a fixed member **163**, and an oil-tight chamber forming member **164**. A second flow path **176** is connected to the high pressure chamber **169**. High pressure fuel is stored in the high pressure chamber **169** through the second flow path **176**.

A pressing chamber **165** is formed in the integral member **162** housed in the high pressure chamber **169**. The pressing chamber **165** houses a portion of the needle **17** (whose configuration is based on the above described embodiment). In addition, a fourth communication passage **166** is disposed in the integral member **162**. High pressure fuel from the high pressure chamber **169** flows in through the fourth communication passage **166**, which is connected to the pressing chamber **165**.

The upper end side in the pressing chamber **165** is referred to as a control chamber **167**, and is a space defined by the needle **17** and the integral member **162**. In addition, the second common orifice **121** (having the same configuration as the second common orifice **121** described in (3) above), which connects the high pressure chamber **169** with the control chamber **167**, is formed in the integral member **162**.

The fixed member **163** is disposed so as to surround the periphery of the integral member **162**. In addition, a plurality of fifth communication passages **175** are disposed in the fixed member **163** such that fuel from the high pressure chamber **169** flows into the fourth communication passage **166**. In addition, the lower end portion of the fixed member **163** is attached to a stepped portion **164**-*a* of the oil-tight chamber forming member **164** (having the same configuration as the fixed member shown in FIG. **15**). Accordingly, the fixed member **163** fixes the oil-tight chamber forming member **164** such that the oil-tight chamber forming member **164** does not move in the axial direction. The upper end portion of the fixed member **163** is attached to a valve cylinder **174**.

An oil-tight chamber **168** is formed of a space defined by the portion of the needle **17** around the lower end of the pressing portion **35**, the lower end portion of the integral member **162**, the oil-tight chamber forming member **164**, and the nozzle body **160**.

The upper end portions of the lower body **161** and the valve cylinder **174** abut the lower end portion of the valve body **170**. A substantially cylindrical valve chamber **170**-*b* is formed in the valve body **170**. A valve spring **171** is housed in the valve chamber **170**-*b*. In addition, a portion of the integral member **162** is inserted through the valve cylinder **174** and into the valve spring **171**. The integral member **162** is slidably supported by the valve cylinder **174**. The valve spring **171** biases the integral member **162** toward the actuator **2**.

A fourth middle chamber **172**, which is a flow path in which fuel flows, is disposed in the integral member **162**. The lower portion of the fourth middle chamber **172** is connected to the control chamber **167**. The upper portion of the integral member **162** is connected to the valve chamber **170**-*b* through a fourth outer orifice **173**. In other words, the integral member **162** connects the control chamber **167** with the valve chamber **170**-*b* through the fourth middle chamber **172** and the fourth outer orifice **173**.

The seating portion **131**, having a configuration based on the example described in (4), is disposed in the valve chamber **170**-*b*. The seating portion **131** is closer to the actuator **2** than the integral member **162** is to the actuator **2**. Specifically, the upper end portion of the seating portion **131** abuts the drive transmission pin **5**, and seats on a seat portion **170**-*b* of the valve chamber **170**-*b* when the actuator **2** is in a contracted state. In addition, a recessed portion, which recesses in a stepped manner toward the actuator **2**, is disposed in the middle of the lower end portion of the seating portion **131**. Meanwhile, a protruding portion, which protrudes toward the seating portion **131**, is disposed in the middle of the upper end portion of the integral member **162**.

Here, the width, in a direction orthogonal to the axial direction, of the recessed portion is formed to be wider than the width, in the same direction, of the protruding portion of the integral member **162**. Accordingly, the lower end portion of the seating portion **131** and the upper end portion of the integral member **162** are fitting to each other in a convex-concave manner with a gap. Here, a height H (width in the axial direction) of the protruding portion of the integral member **162** is designed to be greater than a maximum displacement amount L of the integral member **162** caused by the actuator **2** extending. Accordingly, it is possible to reduce the possibility of the convex-concave fitting between the seating member **131** and the integral member **162** being disconnected.

The operation of the configuration shown in FIG. **33** will be explained. During a low speed valve opening control of the needle **17**, the actuator **2** extends and the drive transmission pin **5** presses the seating portion **131**, causing the seating portion **131** to separate from the seat portion **170**-*c* of the valve chamber **170**-*b*. Accordingly, the low pressure chamber **4**-*b* and the valve chamber **170**-*b* are connected, and the fuel in the control chamber **167** flows into the valve chamber **170**-*b* through fourth middle chamber **172** and the fourth outer orifice **173**. Further, the fuel in the oil-tight chamber **168** is pressurized by the integral member **162**. Due to this, the needle **17** begins moving toward the actuator **2**. Even if the driving of the actuator **2** is stopped, the integral member **162** is movable toward the injection hole **19**. At this time, since the fuel in the high pressure chamber **169** flows through the second common orifice **121** into the control chamber **167** (the same operation as FIG. **23**A), the depressurization speed of the fuel in the control chamber **167** is slowed, and the movement speed of the needle **17** toward the actuator **2** is low.

During a high speed valve opening control of the needle **17**, the actuator **2** extends and the drive transmission pin **5** presses the seating portion **131**, causing the seating portion **131** to separate from the seat portion **170**-*c* of the valve chamber **170**-*b*. Accordingly, the low pressure chamber **4**-*b* and the valve chamber **170**-*b* are connected, and the fuel in the control chamber **167** flows into the valve chamber **170**-*b* through fourth middle chamber **172** and the fourth outer orifice **173**. Meanwhile, the actuator **2** continues to extend, the oil-tight chamber **168** is pressed by the integral member **162**, and the needle **17** moves toward the actuator **2**. Since the needle **17** moves toward the actuator **2**, the control chamber **167** is compressed.

At this time, the rate of fuel pressure increase in the control chamber **167** due to the needle **17** compressing the control chamber **167** is greater than the rate of fuel depressurization in the control chamber **167** due to the fuel in the fuel chamber **167** flowing out into the valve chamber **170**-*b*. As a result, the fuel pressure in the control chamber **167** increases to exceed the fuel pressure of the high pressure chamber **169**. Therefore, in addition of the fuel flowing from the control chamber **167** to the valve chamber **170**-*b*, the fuel in the control chamber **167** also flows through the second common orifice **121** into the high pressure chamber **169** (the same operation as FIG. **23**B). Accordingly, the depressurization speed of the fuel in the control chamber **167** increases, and thus the needle **17** moves at a high speed toward the actuator **2**.

Assume, as in the above described embodiment, that the oil-tight chamber **16** is formed of a space defined by the portion of the needle **17** around the bottom end of the pressing portion **35**, the lower portion of the large-diameter piston **12**, and the portion of the nozzle body **15** penetrated into the lower body **10**. In this case, if the needle **17** moves in a direction that causes fuel to be injected from the injection hole **19** due to the depressurization of the control chamber, the capacity of the oil-tight chamber **16** increases, and the fuel pressure in the oil-tight chamber **16** decreases.

At this time, without the configuration of the integral member **162** shown in FIG. **33**, as the fuel pressure in the oil-tight chamber **16** decreases, only the large-diameter piston **12** moves in a direction the suppresses the fuel pressure in the oil-tight chamber **16** from decreasing. Accordingly, there is a concern that the control valve element **6** may stop blocking the connection between the high pressure chamber **30** and the control chamber **11**. However, with a configuration that includes the integral member **162** shown in FIG. **33**, as the integral member **162** moves in the axial direction the control chamber **11** also moves. Accordingly, as the integral member **162** moves, the control chamber **11** and the high pressure chamber **11** do not connect, and it is possible to suppress the fuel in the high pressure chamber **30** from leaking into the control chamber **11**.

In the above described embodiment, as shown in FIG. **2**, the middle chamber **23** and the outer orifice **24** are formed in the control valve element **6**. The control valve element **6** is able to connect the inside of the valve cylinder **9** with the valve chamber **3**-*b* through the middle chamber **23** and the outer orifice **24**. However, as shown in FIG. **34**, a free piston **180**, which is a piston that is movable in the axial direction within a control valve element **192**, may be disposed in the control valve element **192**. The specific configuration of this is explained next.

A high pressure chamber **184** that houses a valve cylinder **182** and a large-diameter piston **183** is formed in a lower body **181**. A second flow path **185** is connected to the high pressure chamber **184**. High pressure fuel is stored in the high pressure chamber **184** through the second flow path **185**.

A pressing chamber **186** is formed in the large-diameter piston **183**. The pressing chamber **165** houses a portion of a needle **200**. In addition, a first communication passage **187** is disposed in the large-diameter piston **183**. High pressure fuel from the high pressure chamber **184** flows in through the first communication passage **187**, which is connected to the pressing chamber **186**.

The needle **200** includes a small-diameter piston portion **201**, a joint member **201**-*a*, a leak valve **202**, a pressing portion **203**, and a circular column portion **204**. The pressing portion **203** and the circular column portion **204** are integral, while the other members are each separately provided. The nozzle spring **14** is housed in the pressing chamber **186** disposed in the large-diameter piston **183**. The small-diameter piston portion **201** is inserted into the nozzle spring **14**.

A recessed portion **203**-*a* is formed in the middle of the upper end portion of the pressing portion **203**. A protruding portion **203**-*b* that protrudes toward the small-diameter piston portion **201** is formed in the middle of the recessed portion **203**-*a*. The cylindrical joint member **201**-*a* is fitted at the inner periphery of the upper end portion of the pressing portion **203**. The leak valve **202** and a valve spring **205** are housed in the recessed portion **203**-*a* of the pressing portion **203**. The leak valve **202** is biased by the valve spring **205** toward the actuator **2**. Accordingly, the leak valve **202** abuts the lower end portions of the small-diameter piston portion **201** and the joint member **201**-*a*. In addition, a gap is formed between the leak valve **202** and the protruding portion **203**-*b* of the pressing portion **203**.

The lower end portion of the pressing portion **203** is coupled to the circular column portion **204**.

The needle cylinder **13** is disposed at the upper end side in the pressing chamber **186**. The needle cylinder **13** is formed in a substantially cylindrical shape, and is biased toward the actuator **2** by the nozzle spring **14** housed in the pressing chamber **186**. In addition, the pressing portion **203** is biased toward the injection hole **19** by the nozzle spring **14** through the joint member **201**-*a*.

In addition, the control chamber **11** is formed in the needle cylinder **13**. The upper end portion of the small-diameter piston portion **201** is inserted into the control chamber **11**. The small-diameter piston portion **201** is slidably supported by the needle cylinder **13**. A first leak passage **206**, in which fuel flows, is formed in the small-diameter piston portion **201** and opens at the upper and lower portions of the small-diameter piston portion **201**. In addition, a second leak passage **207** is formed in the joint member **201**-*a*. One end of the second leak passage **207** opens into the pressing chamber **186** closer toward the nozzle spring **14**. The other end of the second leak passage **207** opens into the pressing chamber **186** closer toward the leak valve **202**. The upper end portion of the leak valve **202**, which is biased toward the actuator **2** by the valve spring **205**, abuts the lower end portion of the small-diameter piston portion **201**, thereby blocking fuel flowing from the pressing chamber **186** closer toward the leak valve **202** into the second leak passage **207**.

The oil-tight chamber **16** is formed of a space defined by the portion of the needle around the lower end of the pressing portion **35**, the lower portion of the large-diameter piston **12**, and the portion of the nozzle body **15** that protrudes into the lower body **10**.

The valve cylinder **182**, which is substantially cylindrical and which is closer to the actuator **2** than the large-diameter piston **183** is to the actuator **2**, is housed in the high pressure chamber **184**. Further, a cylinder spring **188** is disposed between the valve cylinder **182** and the large-diameter piston **183**. Due to the cylinder spring **188**, the valve cylinder **182** is biased toward the actuator **2**, and the large-diameter piston **183** is biased toward the injection hole **19**.

The upper end portion of the lower body **181** abuts a portion of the lower end portion of the valve body **190**. The lower end portion of the valve body **190** also abuts the upper end portion of the valve cylinder **182**, which is biased toward the actuator **2** by the cylinder spring **188**. A substantially cylindrical valve chamber **191** is formed in the valve body **190**. Further, the valve body **190** includes a hole that communications between the valve chamber **191** and the inside of the valve cylinder **182**. In addition, the valve body **190** includes a hole in communication with the low pressure chamber **4**-*b*.

A portion of the control valve element **192** is inserted into the valve chamber **191**. The control valve element **192** is slidably supported by the valve cylinder **182**. The lower end portion of the control valve element **192** is exposed in the cylinder spring **188**. In other words, the control valve element **192** is housed within the valve body **190**, the valve cylinder **182**, and the cylinder spring **188**.

A protruding portion, which protrudes into the cylinder spring **188**, is formed in the middle of the upper end portion of the large-diameter piston **183**. The area of the upper end portion of this protruding portion is formed to be smaller than the area of the lower end portion of the control valve element **192**. A valve element spring **193** is disposed in a space formed between the cylinder spring **188** and the protruding portion formed on the upper end portion of the large-diameter piston **183**. Due to the valve element spring **193**, the control valve element **192** is biased toward the actuator **2**, and the large-diameter piston **183** is biased toward the injection hole **19**.

For this reason, when the actuator **2** is in a contracted state, the large-diameter piston **183** is biased toward the injection hole **19** by the cylinder spring **188** and the valve element spring **193**. Accordingly, the lower end portion of the control valve element **192** separates from the protruding portion formed in the middle of the upper end portion of the large-diameter piston **183**. In addition, when the actuator **2** extends, the lower end portion of the control valve element **192** abuts with the protruding portion formed in the middle of the upper end portion of the large-diameter piston **183**.

A fourth common orifice **189** is disposed in the large-diameter piston **183**. The fourth common orifice **189** is able to connect the inside of the valve element spring **193** and the control chamber **11** through the protruding portion formed on the upper end portion of the large-diameter piston **183**. For this reason, when the lower end portion of the control valve element **192** is separated from the protruding portion formed in the middle of the upper end portion of the large-diameter piston **183**, the high pressure fuel stored in the high pressure chamber **184** is able to flow through the fourth common orifice **189** and into the control chamber **11**.

Further, a fifth middle chamber **194**, which is a flow path in which fuel flows, is disposed in the control valve element **192**. The lower portion of the fifth middle chamber **194** opens at the lower end portion of the control valve element

192, and is in communication with the inside of the cylinder spring 188. The upper portion of the fifth middle chamber 194 is connected to the valve chamber 191 through a fifth outer orifice 195. In other words, the inside of the cylinder spring 188 and the valve chamber 191 may be connected by the control valve element 192 through the fifth middle chamber 194 and the fifth outer orifice 195.

The fifth middle chamber 194 includes a small-diameter chamber 196 and a large-diameter chamber 197.

The upper portion of the small-diameter chamber 196 is connected to the fifth outer orifice 195, while the lower portion of the small-diameter chamber 196 is connected to the large-diameter chamber 197.

The large-diameter chamber 197 is configured with a greater inner diameter than the small-diameter chamber 196. A small opening portion, which opens toward the small-diameter chamber 196, is formed at the upper portion of the large-diameter chamber 197. A large opening portion, which opens at the lower end portion of the control valve element 192, is formed at the lower portion of the large-diameter chamber 197. The free piston 180, which is movable in a direction that closes the small opening portion, is housed within the large-diameter chamber 197. The outer diameter of the upper end portion of the free piston 180 is configured to be smaller than the outer diameter of the lower end portion of the free piston 180. Here, the area of the upper end surface of the free piston 180 is configured to be sufficient to block the small opening portion formed at the upper portion of the large-diameter chamber 197. Further, the area of the lower end surface of the free piston 180 is configured to be slightly smaller than the cross sectional area of the large-diameter chamber 197.

A piston spring 198 is disposed in the upper portion of the large-diameter chamber 197, between the outer circumferential surface of the free piston 180 and the inner circumferential surface of the large-diameter chamber 197. The piston spring 198 biases the free piston 180 toward the injection hole 19, and when the actuator 2 is in a contracted state, the free piston 180 blocks a portion of the large opening portion formed at the lower portion of the large-diameter chamber 197.

When the actuator 2 is in a contracted state, a gap is formed between the lower end portion of the free piston 180 and the upper end portion of the protruding portion provided on the large-diameter piston 183. Accordingly, the high pressure chamber 184 is connected to the valve chamber 191 through the large opening portion formed in the lower portion of the large-diameter chamber 197, the fifth middle chamber 194, and the fifth outer orifice 195. Further, the high pressure chamber 184 is connected to the control chamber 11 through the fourth common orifice 189.

The drive transmission pin 5 is inserted into the hole formed in the valve body 190. A gap is formed between the drive transmission pin 5 and the hole formed in the valve body 190. The lower end portion of the drive transmission pin 5 abuts the upper end portion of the control valve element 192. The upper end portion of the drive transmission pin 5 protrudes out of the valve body 190.

The configuration of the drive transmission pin 5 on the actuator 2 side is the same as that of the above described embodiments, so explanations thereof are omitted for brevity.

According to the above described configuration, the large-diameter chamber 197 included in the fifth middle chamber 194 houses the free piston 180, which moves in a direction that closes the small opening portion formed in the upper portion of the large-diameter chamber 197. When the actuator 2 is in a contracted state, as shown in FIG. 35A, the control valve element 192 is seated on the upper portion of the valve chamber 191, and thus the low pressure chamber 4-*b* is blocked from the valve chamber 191. During this state, the free piston 180 is biased toward the injection hole 19 by the piston spring 198, and the free piston 180 is not blocking the small opening portion formed at the upper portion of the large-diameter chamber 197. Accordingly, the fuel in the high pressure chamber 184 flows into the large-diameter chamber 197 through the large opening portion formed at the lower portion of the large-diameter chamber 197, and this fuel then flows through the small-diameter chamber 196 and the fifth outer orifice 195 into the valve chamber 191.

Meanwhile, the fuel from the high pressure chamber 184 also flows into the control chamber 11 through the fourth common orifice 189 formed in the large-diameter piston 183. For this reason, the fuel pressure in the control chamber 11 increases, and the needle 200 is pressed toward the injection hole 19. Accordingly, the oil-tight chamber 16 is pressed by the pressing portion 203 of the needle 200, thus pressing the large-diameter piston 183 toward the actuator 2. At this time, the upper end portion of the leak valve 202, which is biased toward the actuator 2 by the valve spring 205, abuts the lower end portion of the small-diameter piston portion 201. Accordingly, the fuel in the control chamber 11 does not flow out through the first leak passage 206 into the pressing chamber 186 closer toward the leak valve 202.

Here, it is supposed that the actuator 2 extends, thereby causing the lower end portion of the large-diameter chamber 197 to abut the upper end portion of the protruding portion provided on the large-diameter piston 183. In this case, as shown in FIG. 35B, the control valve element 192 connects the low pressure chamber 4-*b*, the valve chamber 191, and the control chamber 11 with each other, while blocking the high pressure chamber 184 from the control chamber 11. Accordingly, the fuel in the control valve element 192 flows out through the fifth outer orifice 195 into the low pressure chamber 4-*b*, and the fuel pressure in the control valve element 192 decreases. As this pressure decreases, the free piston 180 moves in a direction of closing the small opening portion formed at the upper portion of the large-diameter chamber 197, and during that time, the fuel pressure in the control chamber 11 decreases.

Then, once the free piston 180 blocks the small opening portion formed at the upper portion of the large-diameter chamber 197, the fuel in the control valve element 192 stops flowing out through the fifth outer orifice 195 into the low pressure chamber 4-*b*, and the fuel pressure in the control chamber 11 stops decreasing. Due to this, the fuel pressure in the control chamber 11 may be kept constant, and the movement amount of the needle in a direction that causes fuel to be injected from the injection hole 19 may be limited.

When the extension amount of the actuator 2 is large (a high speed opening of the needle 200), the large-diameter piston 183 is pressed by the control valve element 192, and the oil-tight chamber 16 is pressed by the large-diameter piston 183. For this reason, the fuel in the oil-tight chamber 16 presses the pressing portion 203, which contacts the oil-tight chamber 16, toward the actuator 2, and thus the small-diameter piston portion 201 moves toward the actuator 2. Accordingly, the control chamber 11 is compressed by the small-diameter piston portion 201, and the fuel pressure in the control chamber 11 increases. A this time, the free piston 180 is blocking the small opening portion formed at the upper portion of the large-diameter chamber 197, thus the pressure in the control chamber 11 is not released into the low pressure chamber **4**-*b*. Meanwhile, since the leak valve **202** moves toward the injection hole **19**, a gap is created between the lower end portion of the small-diameter piston portion **201** and the upper end portion of the leak valve **202**. In other words, the control chamber **11** is connected to the pressing chamber **186** through the first leak passage **206**, this gap, and the second leak passage **207**. Accordingly, the fuel in the control chamber **11** may flow out through the first leak passage **206** and the second leak passage **207** into the pressing chamber **186**, and thus the fuel pressure in the control chamber **11** may be quickly decreased.

The invention claimed is:

1. A fuel injection valve, comprising;

a body including

a first chamber that supplies fuel at a first pressure,

a second chamber that supplies fuel at a second pressure, the second pressure being lower than the first pressure, and

an injection hole;

a valve chamber member including a valve chamber, the valve chamber being connectable to the first chamber and the second chamber;

a control chamber member including a control chamber, the control chamber being connectable to the first chamber;

a needle, the needle being pressed by pressure of fuel in the control chamber in a direction that causes fuel injection from the injection hole to stop;

an actuator driven to extend and contract;

a valve element that

blocks the second chamber from the valve chamber and connects the first chamber, the valve chamber, and the control chamber with each other when the actuator is in a contracted state, and

changes position when the actuator extends to connect the second chamber, the valve chamber, and the control chamber with each other and block the first chamber from the control chamber; and

a transmission mechanism that transmits a force generated by the actuator extending, which causes the valve element to displace, to the needle as a force in a direction that causes fuel to be injected from the injection hole.

2. The fuel injection valve of claim **1**, wherein

a portion of the needle that receives the pressure of the fuel in the control chamber has a projection area, projected in a movement direction of the needle, that is smaller than a projection area, projected in the movement direction of the needle, of a portion of the needle exposed to the injection hole.

3. The fuel injection valve of claim **1**, further comprising:

a valve biasing member that biases the valve element toward the second chamber.

4. The fuel injection valve of claim **1**, wherein

a common orifice is formed in a particular component of the transmission mechanism, the common orifice regulating an amount of fuel flowing into the control chamber and regulating an amount of fuel flowing out of the control chamber.

5. The fuel injection valve of claim **1**, wherein

an outer orifice is formed in the valve element, the outer orifice regulating an amount of the fuel flowing out from the control chamber into the valve chamber.

6. The fuel injection valve of claim **1**, further comprising:

a substantially cylindrical cylinder that, together with the valve chamber member, is disposed so as to separate the valve element from the first chamber.

7. The fuel injection valve of claim **6**, further comprising:

a cylinder biasing member that biases the cylinder toward the valve chamber member.

8. The fuel injection valve of claim **1**, wherein

the transmission mechanism includes

a nozzle body that slidably supports the needle,

a piston that houses a portion of the needle, the piston abutting an end surface of the needle toward the actuator when a movement amount of the needle in the direction that causes fuel to be injected from the injection hole exceeds a first predetermined amount, the first predetermined amount being set to be lower than a maximum movement amount.

9. The fuel injection valve of claim **8**, further comprising:

an increase mechanism between the actuator and the valve element, the increase mechanism increasing a displacement amount by which the valve element is displaced due to the actuator extending.

10. The fuel injection valve of claim **9**, wherein

the increase mechanism includes

a large-diameter pin connected to an end portion of the actuator toward the injection hole,

a support cylinder that slidably supports a portion of the large-diameter pin, and

a valve element contact pin slidably supported in the support cylinder, the valve element contact pin being moveable to press the valve element toward the injection hole,

a displacement amplification chamber is formed by the support cylinder, the large-diameter pin, and the valve element contact pin,

the large-diameter pin transmits a driving force from the actuator to the valve element contact pin through fuel in the displacement amplification chamber, and

an area of a portion of the large-diameter pin that presses on the fuel in the displacement amplification chamber is greater than an area in which the fuel in the displacement amplification chamber presses on the valve element contact pin.

11. A controller that controls the fuel injection valve of claim **8**, wherein

upon the movement amount of the needle in the direction that causes fuel to be injected from the injection hole exceeding the first predetermined amount, the controller controls the piston to regulate the movement amount of the needle due to the actuator being driven to extend and contract.

12. The controller of claim **11**, wherein

the controller regulates the movement amount of the needle based on the fuel pressure in the control chamber during a first stage injection and a last stage injection of a multi-stage injection, the multi-stage injection being performed as a plurality of fuel injections during one combustion cycle of an internal combustion engine, and

the controller controls the piston, which is maintained in a state of abutting the end surface of the needle toward the actuator, to regulate the movement amount of the needle due to the actuator being driven to extend and contract during all injections of the multi-stage injection other than the first injection and the last injection.

13. The fuel injection valve of claim **1**, wherein

the transmission mechanism includes

a nozzle body that slidably supports the needle, and

a piston that, together with the needle and the nozzle body, forms an oil-tight chamber, wherein the piston transmits a driving force of the actuator through fuel in the oil-tight chamber to the needle.

14. The fuel injection valve of claim **13**, wherein

an area of a portion of the piston that presses on the fuel in the oil-tight chamber is greater than an area of a portion of the needle pressed against by the fuel in the oil-tight chamber in the direction that causes fuel injection from the injection hole to stop.

15. The fuel injection valve of claim **1**, wherein

the transmission mechanism includes

a nozzle body that slidably supports the needle,

a piston that houses a portion of the needle, and

a second cylinder housed in the piston so as to surround the needle, the second cylinder, together with the needle and the nozzle body, forming an oil-tight chamber, wherein

the second cylinder includes a second cylinder end portion toward the actuator,

a first gap exists between the second cylinder end portion and a surface of the piston that faces the second cylinder end portion,

the piston transmits a driving force of the actuator through fuel in the oil-tight chamber to the second cylinder and the needle when the first gap exists, and

the piston and the second cylinder transmit the driving force of the actuator through fuel in the oil-tight chamber to the needle when the first gap is closed.

16. The fuel injection valve of claim **15**, wherein

a quotient obtained by dividing i) an area of a portion of the piston that presses on the fuel in the oil-tight chamber by ii) a total area of portions of the needle and the second cylinder pressed on by the fuel in the oil-tight chamber is greater than a quotient obtained by dividing i) a total area of the portions of the piston and the second cylinder that press on the fuel in the oil-tight chamber by ii) an area of the portion of the needle pressed on by the fuel in the oil-tight chamber toward the actuator.

17. The fuel injection valve of claim **1**, wherein

the transmission mechanism includes

a nozzle body that slidably supports the needle,

a third cylinder supported by the nozzle body, and

a piston that, together with the third cylinder and the nozzle body, forms an oil-tight chamber, wherein

the piston transmits a driving force of the actuator through fuel in the oil-tight chamber to the third cylinder, and

the third cylinder abuts the needle to transmit the transmitted driving force to the needle as a force in the direction that causes fuel to be injected from the injection hole.

18. The fuel injection valve of claim **1**, further comprising:

a piston biasing member, wherein

the valve element includes

a second chamber connection member that blocks the second chamber from the valve chamber and connects the first chamber with the valve chamber when the actuator is in the contracted state, and changes position when the actuator extends to connect the second chamber with the valve chamber, and

a first chamber connection member that separates from the second chamber connection member when the actuator is in the contracted state to connect the first chamber with the control chamber, and abuts the second chamber connection member when the actuator extends to connect the valve chamber with the control chamber and to block the first chamber from the control chamber,

the transmission mechanism includes

a nozzle body that slidably supports the needle, and

a piston that, together with the needle and the nozzle body, forms an oil-tight chamber,

the piston transmits a driving force of the actuator through the first chamber connection member and the second chamber connection member,

the piston is biased by the piston biasing member toward the actuator to abut the first chamber connection member,

the control chamber member includes a control chamber member end portion toward the actuator, and

a second gap exists between the control chamber member end portion and a surface of the piston that faces the control chamber member end portion when the piston is abutting the first chamber connection member.

19. The fuel injection valve of claim **18**, wherein

a width of the second gap between the piston and the control chamber member is greater than a value calculated by dividing i) a maximum movement amount of the needle in the direction that causes fuel to be injected from the injection hole by ii) a quotient obtained by dividing an area of a portion of the piston pressing on fuel in the oil-tight chamber by an area of a portion of the needle pressed on by the fuel in the oil-tight chamber in the direction that causes fuel to be injected from the injection hole.

20. The fuel injection valve of claim **1**, wherein

an end surface of the control chamber member toward the actuator is exposed in the control chamber.

21. The fuel injection valve of claim **20**, wherein

a second outer orifice connected to the first chamber is provided, the second outer orifice being connected to the control chamber during an abutting state and being blocked from the control chamber when the abutting state is canceled,

the abutting state exists when the end surface of the control chamber member toward the actuator abuts an opposing surface of the control chamber, the abutting state being canceled when the control chamber member moves toward the injection hole, and

the second outer orifice is the only path through which fuel in the control chamber flows out into the first chamber when the abutting state is canceled.

22. The fuel injection valve of claim **1**, wherein

a second common orifice in communication with the first chamber is connected to the control chamber.

23. The fuel injection valve of claim **1**, wherein

the valve element includes

a sliding portion that connects the first chamber, the valve chamber, and the control chamber with each other when the actuator is in the contracted state, and changes position when the actuator extends to block the first chamber from the control chamber and to connect the control chamber to the valve chamber, and

a seating portion that is movable in an axial direction while abutting an end surface of the sliding portion toward the actuator, the seating portion blocking the second chamber from the valve chamber when the actuator is in the contracted state, and changing position when the actuator extends to connect the second chamber with the valve chamber.

24. The fuel injection valve of claim 23, wherein an outer orifice is formed in the sliding portion, the outer orifice regulating an amount of the fuel flowing out from the control chamber into the valve chamber.

25. The fuel injection valve of claim 23, wherein the transmission mechanism includes

a nozzle body that slidably supports the needle, and

a piston that, together with the needle and the nozzle body, forms an oil-tight chamber, and

the piston, the control chamber member, and the sliding portion are integrally provided.

26. The fuel injection valve of claim 23, wherein a surface of the seating portion that contacts the valve chamber when the actuator is in the contracted state is formed as a spherical surface.

27. The fuel injection valve of claim 23, wherein the sliding portion and the seating portion include complimentary protruding and recessed portions that fit with each other in a convex-concave manner such that surfaces of the sliding portion and the seating portion are in contact with each other with a gap.

28. The fuel injection valve of claim 27, wherein a height of the protruding portion of the complimentary protruding and recessed portions is greater than a maximum movement amount of the sliding portion.

29. The fuel injection valve of claim 1, wherein

an outer orifice is formed in the valve element to regulate an amount of the fuel flowing out from the control chamber into the valve chamber, and

a second piston is housed in the valve element, the second piston being movable in a direction to prevent fuel from flowing through the outer orifice into the second chamber.

30. The fuel injection valve of claim 1, wherein the actuator is formed of piezo elements.

31. A controller that controls the fuel injection valve of claim 1, wherein

the controller includes a first charge control mode and a second charge control mode which differ in charge energy timing, the charge energy timing being defined as when reaching a required amount of charge energy from a start of charging the actuator until the needle causes fuel to be injected from the injection hole,

during the first charge control mode, the charge energy timing is set to be later than a depressurization completion timing, the depressurization completion timing being when the control chamber is depressurized to a predetermined pressure required for the needle to cause fuel to be injected from the injection hole, and

during the second charge control mode, the charge energy timing is set to be earlier than a depressurization completion timing.

32. The controller of claim 31, wherein the first charge control mode is configured to have a greater final charge energy ultimately charged to the actuator as compared to the second charge mode.

33. The control of claim 31, wherein the first charge control mode is configured to have an earlier connection operation energy timing as compared to the second charge control mode, the connection operation energy timing being when reaching a connection operation energy required for the valve element to block the control chamber from the first chamber and to connect the valve chamber with the second chamber.

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